MEGADRIVE-LCI
System Description

Project:

Product: MEGADRIVE – LCI.DR

ABB-Order No.:

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Appr				
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1 Introduction

Adjustable-speed drive systems, based on AC machines, are being used in a growing field of applications to save energy and also to improve process control for more cost-effective operation of the processes.

The MEGADRIVE-LCI (Load (machine) Commutated Inverter) system, based on synchronous machines and converters with naturally commutated thyristors, is one of the most efficient drive systems that exist. This is due to the high efficiency of the synchronous machine, typical value 97% and of the converter with 99% efficiency.

The MEGADRIVE-LCI is used for high power, mainly single-motor drive applications and also in conjunction with high speed requirements. Its performance is, in many aspects, similar to that of a DC drive. Two-quadrant operation can be obtained without any further equipment. Torque generation is very smooth, especially with designs for twelve-pulse operation on the motor side.

The MEGADRIVE-LCI is well suited for a great number of applications in industrial as well as power generating plants. These are principally continuously running drives for fans and pumps, high speed and reciprocating compressors, boiler feed pumps and wind tunnel blowers but also for rolling mills, extruders, etc.

This type of converter has practically no restrictions on the maximum design power and the output frequency. The ABB MEGADRIVE-LCI system is available in the power range of 1 000 kW to 46 000 kW. The system is also suitable for high-speed applications with turbo machines up to approximately 7000 rpm.

The converter equipment, designed in accordance with the international standard IEC, is largely standardized and based on modular mechanical and electrical designs. This applies to both the power part and the control hardware, as well as for the control software. The *standard converters,* cooled by water, *cover the power range* from approximately *3 to 46 MW*, with the voltage range extending up to 2*7 kV, depending on the power rating. Because of their modularity, these standard MEGADRIVE-LCI converters are flexible enough to cope with the various application-specific demands made upon them. Nevertheless, their use considerably simplifies and shortens factory testing, erection, commissioning and servicing.

2 Main features and significant benefits

In addition to the usual advantages, variable speed and especially electrical adjustable speed offers, for instance,

- elimination of damper and throttle valves
- improved process control with better dynamic performance
- energy savings, thanks to better matching of the drive power to the momentary demand of the driven machine.
- low maintenance
- low noise, compared to both damper and throttle valves

The MEDGADRIVE-LCI drive system has many unique benefits:

- *High efficiency*, also at part load
- *High reliability* and availability, based on robust and modular design
- *Low maintenance* due to static frequency converter in combination with brushless motor
- Well suited for *high power / high speed*
- *Safe in hazardous areas*
- *Gentle starting*, with controlled starting torques and without inrush currents
- *Insensitive to* brief power *supply failures*
- *Wide speed control range*
- Inherent *regenerative* motor *breaking (two-quadrant operation)*
- *Low noise* level compared to mechanical or hydraulic drives
- *Flexibility in plant layout*

3 Basic circuit and principle of operation

3.1 Principle of operation

The LCI system is a current source type of drive. A basic circuit diagram is shown in Figure 1.

The synchronous motor receives its power via an isolating transformer and a static frequency converter, which is set up according to the DC link configuration of the current source type. Two identical thyristor converters in three-phase bridge connection form the basis of the scheme.

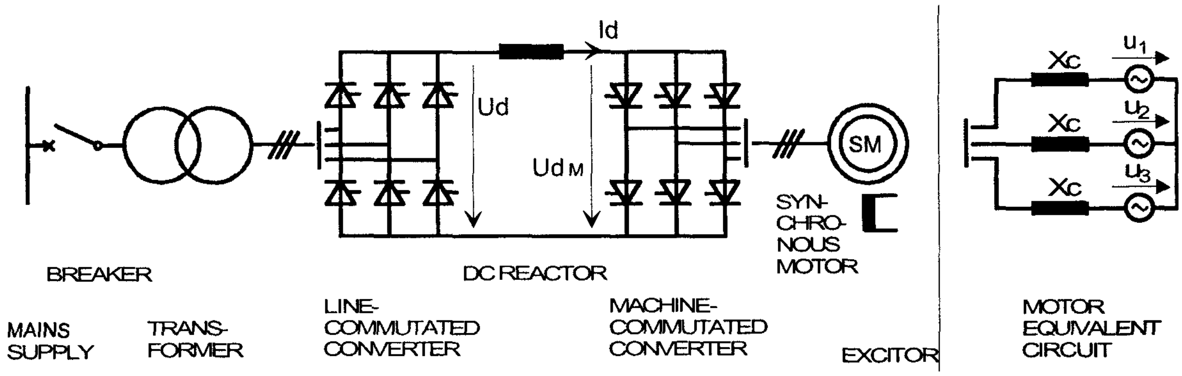


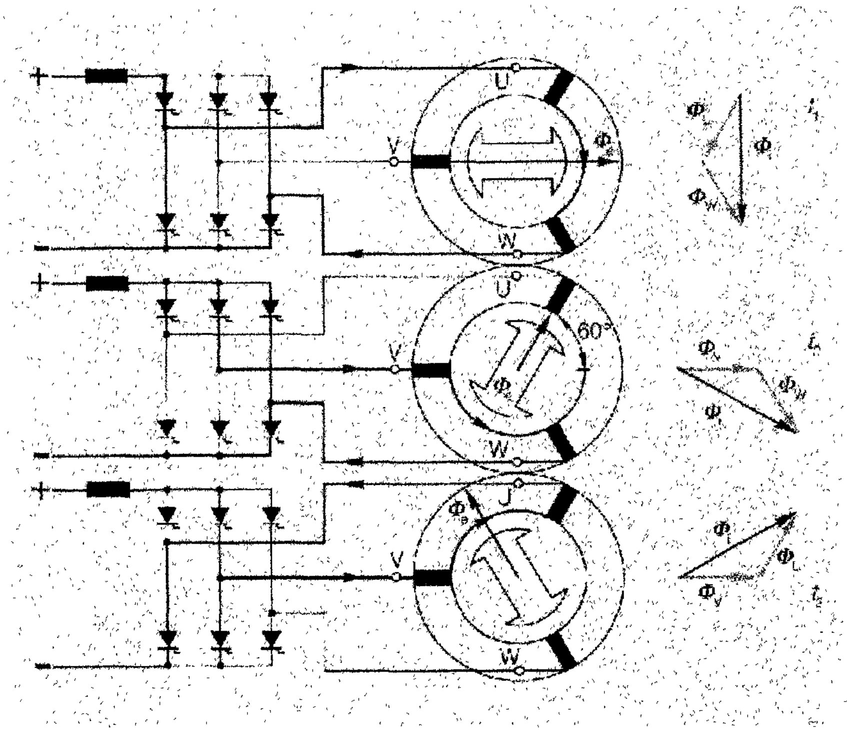
Fig. 1: LCI system, basic circuit diagram

One converter is connected via transformer to the mains supply; it is "line commutated" and operates at constant frequency. The other converter connected to the synchronous motor is "load (machine) commutated" and is operated with variable frequency. Thus the load has to supply the reactive power required for control and commutation of this converter. The over-excited synchronous motor fulfils these conditions. (For reflection purposes, it is favorable to replace the machine by a three-phase sinusoidal voltage source behind a certain commutation reactance X_C, Figure 1).

The two converters are interconnected through the DC reactor in the intermediate circuit, which limits the current harmonics and the rate of current rise in case of a failure.

The synchronous machine can operate either as a motor or as a generator. When the machine operates as a motor, the line converter acts as a rectifier providing current control, the machine converter as an inverter commutating the current between the motor phases. Generating mode can be achieved without any extra equipment in the converter. When the machine works as a generator, the machine converter acts as a rectifier and the line converter an inverter; in this way the flow of energy is reversed.

The thyristors in the machine converter cause the current at any time to flow through two phases of the three-phase stator winding. Figure 2 shows a synchronous machine with the three stator windings displaced by 120° and the current path at the time intervals t_1, t_2 and t_3. The magnetic flux ϕ_i produced by the stator windings rotates 60° every time another pair of thyristors in the machine converter is fired. The exciter supplies current to the exciter winding of the rotor, which produces the rotor flux ϕ_e. The result is an electromagnetic torque whose value reaches a maximum when the magnetic flux ϕ_e from the exciter winding is perpendicular to the flux ϕ_i produced by the stator windings. This torque turns the rotor 60° whenever a pair of thyristors in the machine converter is fired.



t_1, t_2, t_3	Time interval
U, V, W	Phases of the synchronous machine
ϕ_i	Magnetic flux produced by stator windings
ϕ_e	Magnetic flux produced by exciter winding

Fig. 2 A synchronous machine fed via an LCI

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3.2 Commutation and Control at low speed/frequency

The machine converter is load (machine) commutated, meaning it relies on the machine voltages for commutation and control. At zero and very low speed/frequency, the motor voltage is too low for machine commutation and control of the machine converter directly from the motor voltages.

a) Commutation of machine converter at low speeds with "pulse mode operation"

A simple solution, named "DC pulsing mode" has become the standard commutation method in the speed range from zero to n_a (about 10% of rated speed), see Figure 3 / upper part. In this speed range the commutation is not performed by the motor voltages but by line-commutated pulsing of the DC link current (Pulse mode). Each time the current in the machine converter is required to commutate, the firing pulses to the line converter are phase retarded during a few milliseconds; the DC current is thus forced to zero, which means that the conducting thyristors will be switched off and the firing pulses to the machine converter can be blocked. After some milliseconds, the machine converter firing pulses are released to the next pair of thyristors and the line converter is phase advanced again. In this mode of operation, the DC current is periodically reduced to zero for a few milliseconds, which means that the torque produced in the machine also disappears during these time intervals. This takes effect as torque pulsations. *A torsional study of the mechanical system is generally required for the LCI drives. Thereby the low speed range, where the converter operates in the "DC pulsing mode", is of special importance.*

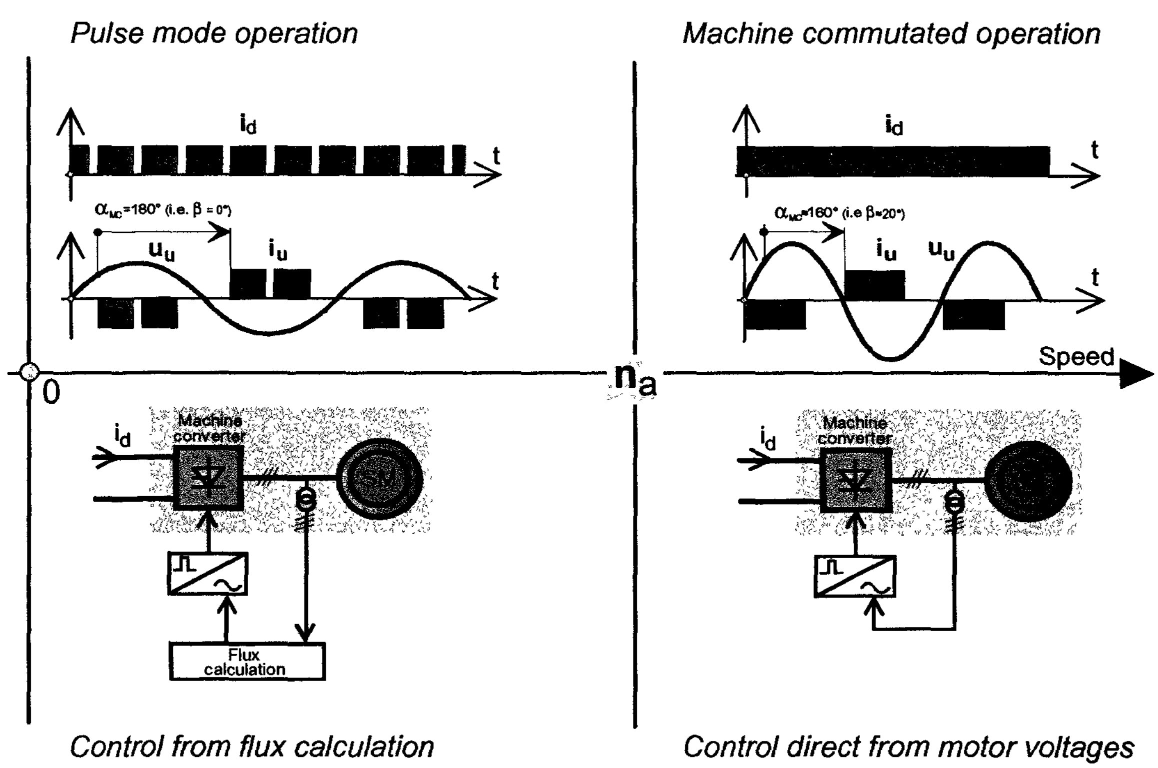

Fig. 3: Commutation and control principle of machine converter at low and high speed

b) Control of machine converter at low speeds with "Flux calculation"

The firing pulses for the machine converter are determined using the measured machine voltages. In the speed range from zero to n_a (about 10% of rated speed), see Fig. 3 / lower part, the LCI-controller calculates in a machine model out of the measured machine voltages u_m the motor flux signals ϕ ($\phi = \int u_m$). To get correct flux-signals, the flux calculation has to be started with the release of the excitation current. The calculated flux vector (with constant amplitude) is perpendicular to the machine voltage vector (with low amplitude at low speeds) and therefore the flux signals can be used to determine the firing pulses.

3.3 Similarity of LCI- and DC-drive

The similarity of the LCI-system to the converter-controlled DC machine becomes evident (Figure 4). The DC current and thereby torque and speed, are controlled by the line converter in exactly the same manner as for the DC motor drive. The firing pulses for the machine converter are derived from the machine voltages and are thereby in phase relation to the angular position of its rotor (self control mode). So this converter operates as an electronic commutator. In the LCI system the synchronous machine is fully self-controlled and hunting or loss of synchronism are ruled out.

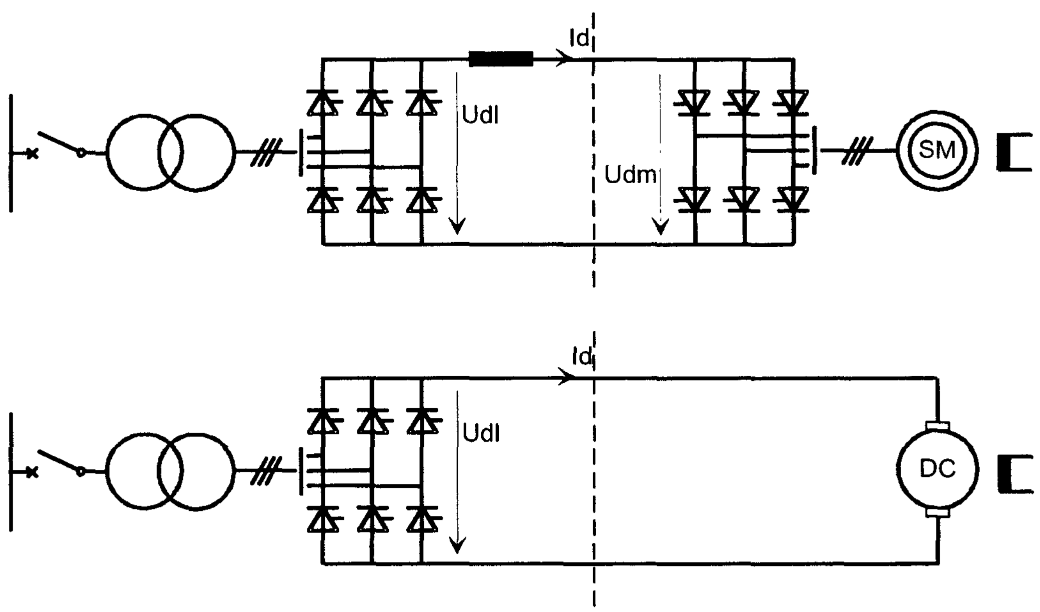

Fig. 4: Similarity of LCI- and DC-drive

4 Control system concept and functional description

4.1 Control system concept

The LCI control system is microprocessor based. The digital control devices put to use include not only the microprocessor-based programmable controller, the "core " of the control, but also other large scale integrated components as, for instance, used in the gate trigger devices.

Digital control in the LCI is used mainly for: torque control, speed control, complex protection functions, sequence control for normal switch-on and switch-off, emergency switch-off, as well as drive monitoring and diagnostic functions in general. All these tasks are fully performed by a *general purpose microcontroller*, which is specially designed for use in converter-controlled adjustable-speed AC drives. It offers a high degree of flexibility and is, because of its variable or programmable control structure, well adapted to different applications.

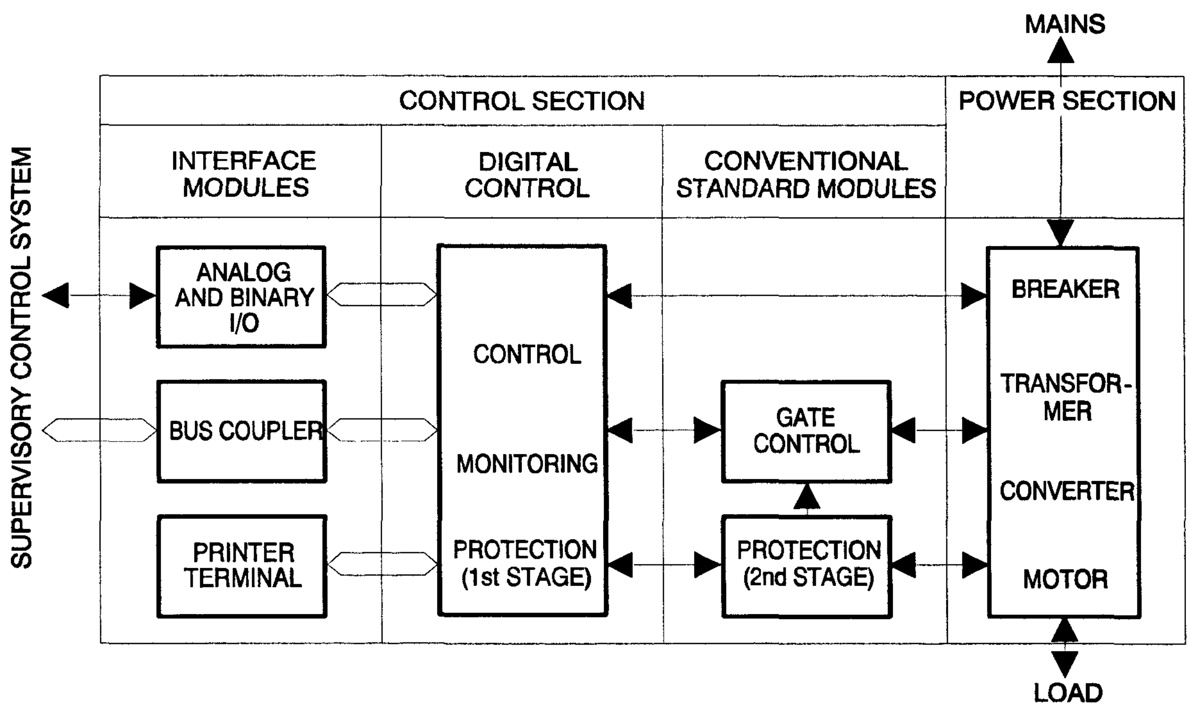

Fig. 5: LCI Control concept

Figure 5 illustrates the typical *hardware concept* of the LCI drive control system. The control is divided into 3 subsections:

- The central subsection basically comprises programmable functions. Its HW consists mainly of a micro-controller module (the "core"), associated I/O-boards and interface units. These board modules communicate via a fast parallel bus. With modern, high performance microprocessor components, the internal architecture of the micro-controller is designed and optimized, so that it not only operates fast enough for adjustable-speed AC drive applications but also facilitates the implementation of a problem-oriented and user-friendly programming language.
- A further means used to attain the processing speed required for time critical control functions, is optimum task/time management. To achieve this, the principle of time sharing between several tasks, which are processed at different repetition rates and have different interrupt priorities, is applied. Critical control algorithms, such as current controllers, are given priority at the expense of less time-critical functions, such as on/off sequences and monitoring, which are infrequently processed.
- The right hand subsection in Figure 5 comprises standard modules for converter gate control and certain backup protection functions.
- The left hand subsection includes the interfaces for signal exchange between control, "process" and "outside".

The use of digital techniques has brought many benefits, for instance:

- higher accuracy (no drifts with time, aging, temperature etc.)
- more extended, continuous drive monitoring
- better man/machine communication and
- expanded communication capability.

4.2 Functional description of control

The control comprise the following functional groups:

- the sequence control
- the regulation (mainly closed loop controls)
- the protection and monitoring functions
- the communication

a) The sequence control

The purpose of the sequence control is to take care of starting ("Drive ON") and stopping ("Drive OFF") the drive in the right sequence. Automatic start-up of the drive (accelerating the motor to set speed) and automatic shut-down (by interrupting power to the motor so it can coast to stop) takes place in an orderly manner. Both sequences are split into the several steps with intermediate necessary supervision for correct functioning. The sequence control also includes the emergency shutdown logic in case of a failure in the drive.

The LCI drive has software-based sequencing, implemented in the programmable high-speed controller PSR.

The drive may be operated from the customer's remote station (e.g. central control room) or from the operator's local panel on the converter control cubicle (e.g. for commissioning and servicing). When local control is selected, remote control inputs do not function and vice versa. The standard communication link with the remote control is by parallel signal interface.

b) The regulation

This passage only gives an outline of the regulation principle. The most important regulation functions of the LCI drive system are the feedback and feed forward controls. These controls act on the following three power controllers (Figure 6):
- the line converter
- the machine converter and
- the AC power controller (for excitation)

- *The speed controller* (1) with the inner *current control* loop (2) is a classic cascade feedback arrangement. The speed controller supplies the current controller with the set value necessary to attain, respectively to maintain the required speed. In first approximation it can be assumed that the torque developed by the synchronous motor is proportional to the dc current, to the motor flux and to the motor displacement factor cos phi. Accordingly, the current controller indirectly adjusts the torque exerted at the shaft of the motor by varying the DC voltage of the line converter.

- *β-control* (3) is a feed forward control function, setting the firing angle $\alpha = 180° - \beta$ of the machine converter, which is also in rough approach equal to the displacement factor cos phi of the motor.

  The firing pulses for the machine converter are derived from the machine voltages and are thereby in phase relation to the angular position of its rotor (self control mode). The machine is fully self-controlled and hunting and loss of synchronism are ruled out. The similarity to the converter-controlled DC machine becomes evident.

  The inverter advance angle β is set to a value which provides a sufficient margin angle for commutation (overlapping time, thyristor recovery time and safety margin). The strategy for the optimal β-control is to maximize efficiency, performance and displacement factor cos phi, while minimizing motor heating. To this end, the advance angle β is generally adjusted as a function of current i_{dx} and speed n_x.
  Remark:
  - too low β may lead to a commutation failure (overcurrent);
  - too big β leads to a low cos phi at the motor with the following consequences:
  - a low cos phi at the motor has to be compensated with a higher motor current und thus with lower efficiency
  - with maximum motor current the required shaft power may not be reached
  - a lower cos phi at the motor leads to smaller DC voltage and therefore to a lower cos phi at the line converter.

- *The voltage controller* (4) with the inner *current control* loop (5) is also a classic cascade feedback arrangement. The voltage controller supplies the current controller with the set value to attain and to maintain the required voltages u_{mw} at the motor terminals. In principle these voltages are adjusted proportionally to the motor speed n_x, so that the machine flux remains at its nominal value. The current controller (5) indirectly adjusts the current of the brushless exciter by varying the AC voltages at the exciter-stator via the AC power controller.

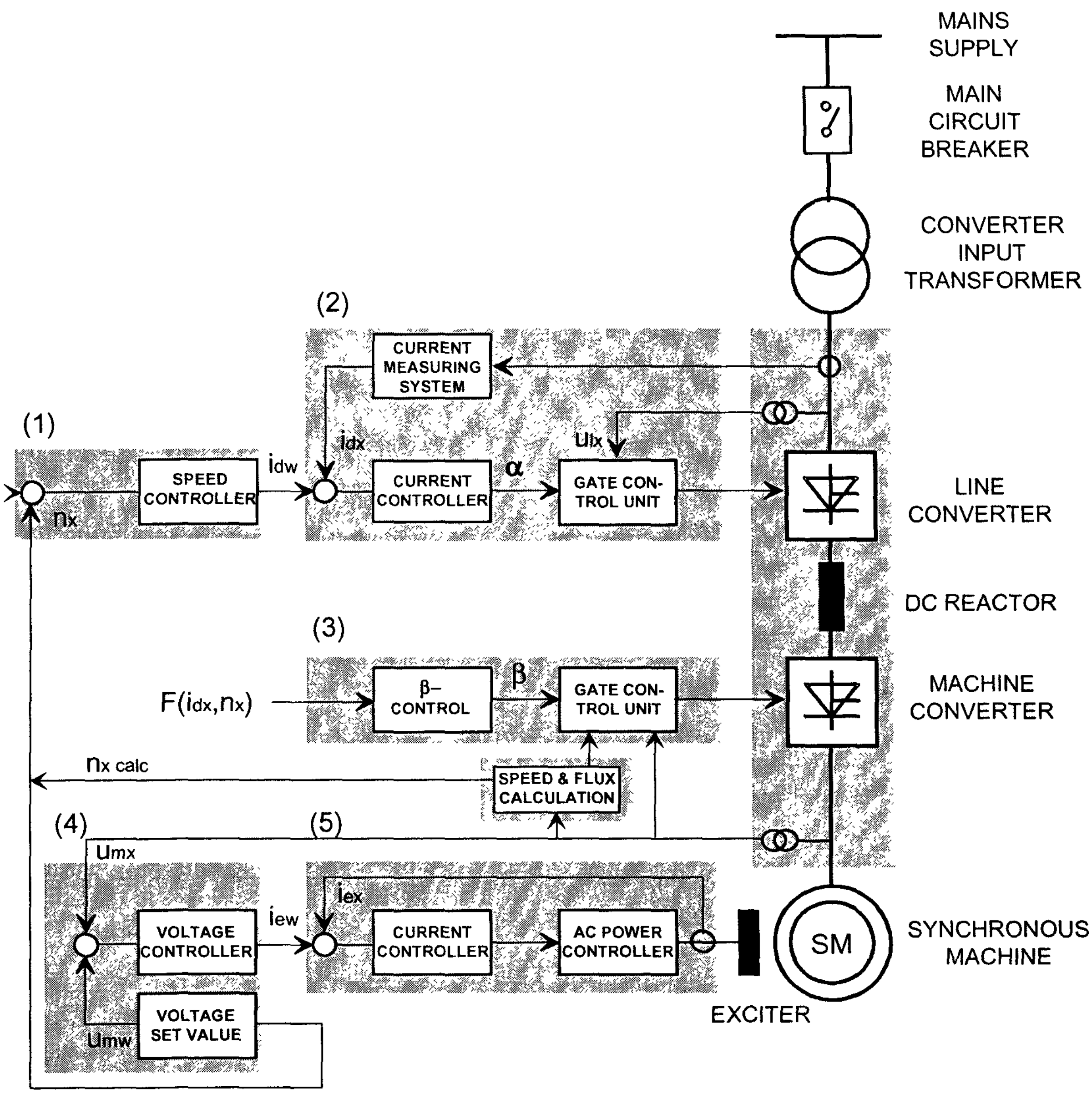

Fig. 6: The LCI regulation functions

c) The protection and monitoring functions

These functions ensure that electrical, mechanical and thermal limits of the drive system are not exceeded and they also indicate any irregularities in order that these may be quickly diagnosed.

Protection and monitoring are realized as software functions in the programmable high speed controller PSR. The most important protection functions are also implemented in a hardware backup protection equipment.

Common trip and alarm signals are generated and sent to all relevant devices in order to initiate a shutdown or, if necessary, to trip the drive. For indication purposes, they are also sent to the operator's panel and the remote control. Fault messages are given in plain language on the operator's panel, with indication of first fault and consecutive faults.

A large number of protective and monitoring functions are provided in the drive system. The following (see Figure 7) are included in the *standard* LCI drives:

- *Motor*

Electrical:	Overvoltage and undervoltage, overfrequency (=overspeed).

- *Converter*

Electrical:	Mains undervoltage, converter overcurrent, earth fault power section. Monitoring of different fuses and mini circuit breakers.
Cooling:	Water temperature, level, flow and conductivity
Control:	General failures of control electronics.
Excitation:	AC power controller overcurrent.
Auxiliary supply:	Aux undervoltage.
DC reactor:	Water temperature

- *Converter input transformer:*

- oil cooled type:	oil temperature, oil level and Buchholz
-dry type:	winding overtemperature

- *Main switchgear:* normally autonomous overcurrent.

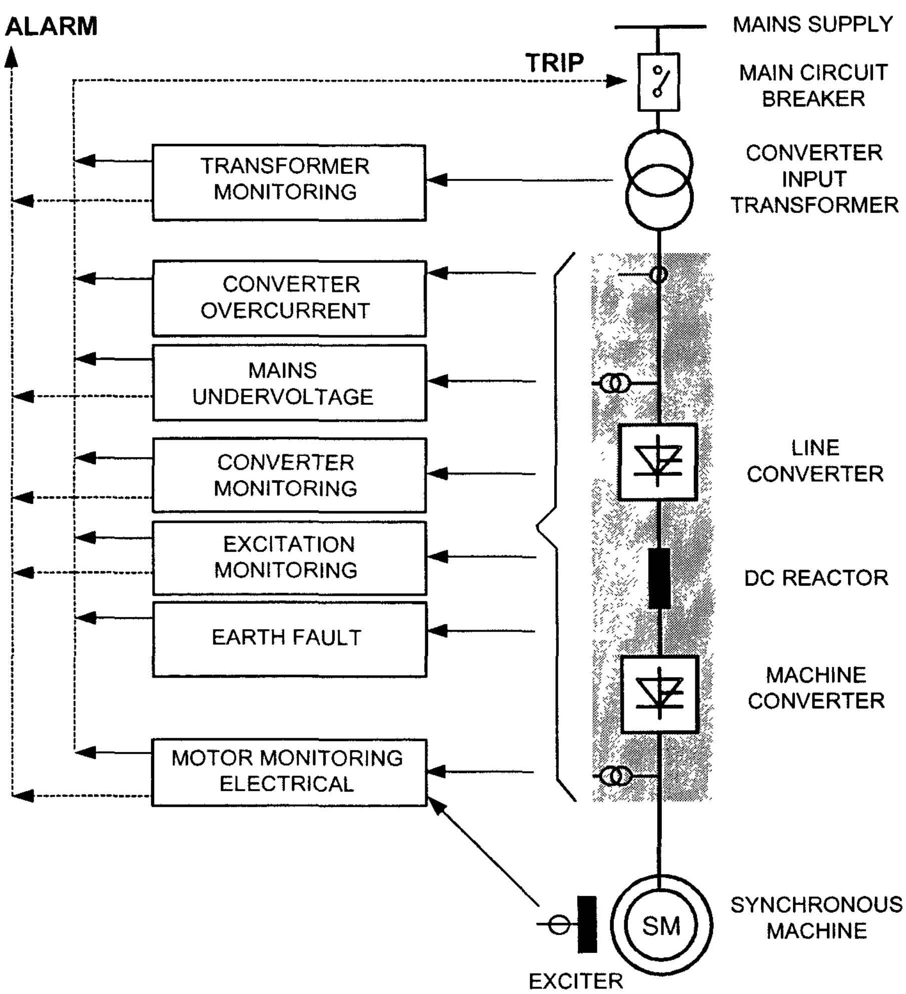

Fig. 7: The LCI protection and monitoring functions

d) The communication and drive interfaces

Whereas the programmable high speed controller PSR communicates with its neighbouring board modules via a fast parallel bus which can handle the fast data transfers needed for many control functions, the communication between the control and the converter and other drive system components, as well as the communication with a superimposed or any other remote control, can be done via parallel wired or fast serial connections.

The standard LCI design enables its connection to any superimposed control by means of parallel input and output interfaces. The following are available as a *standard* :

- *one analog input* (n_W) and *one analog output* (n_X)
- *10 binary inputs* and *9 binary outputs* for the essential binary signals as, for example, "drive on", "drive off", etc.

Specialized serial interface devices enabling the serial data exchange with various superimposed control systems are available *as options.*
Available are the following interface links: Modbus and Allen Bradley PLC2.

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5 Input power factor

The line converter of the LCI has the main circuit configuration and operational features identical to the common converter used for DC drives. The DC current is regulated by phase control of the line converter. Consequently, the reactive power consumption and the input power factor dependence on drive operation is also similar to that of the DC drive. Thus the input power factor and input kVAR will change when the speed and load of the drive change. The power factor is low at low speed and reaches its maximum value at rated speed.

Both the input power factor and input kVAR for the LCI system can consequently be calculated in the same manner as for a DC drive. The power factor is typically between 0.80 and 0.90 at rated speed and rated load.

6 Harmonics

The LCI drive, like all other drive systems utilizing static converter equipment, generates harmonic currents which are forced upon the supply network and upon the synchronous machine. Since the line converter is operated in the same manner as the equivalent DC drive, the same methods of estimating and calculating the harmonics impressed on the supply network can be applied.

With the LCI drive there are two categories of harmonics: The *integer harmonics* and the *non-integer harmonics.*

Not only the supply network is affected by the corresponding harmonic currents but the machine will also be affected. The current in the DC link will not be completely smooth, even if there is a reactor. The voltage harmonics of constant frequency in the line converter DC voltage and those of variable frequency in the machine converter DC voltage, produce non-characteristic ripples in the DC current. This results in additional, non-integer harmonics in the line currents, in the machine currents and in the electrical torque of the machine.

Although these harmonics are very small, the responsible designer for the complete mechanical drive system should have these in mind and check their influence on the mechanical system. In the majority of applications (compressors, pumps and fans), the frequencies of the integer harmonics in the pulsating torque are much higher than the resonance frequency of the mechanical system, whereas the frequencies of the non-integer harmonics may well occur in a range where the lowest natural frequency of the mechanical system is located.

One way of reducing the harmonic currents on both the line side and the machine side, is to split the converter into two converters operating 30° phase displaced with respect to each other. Such a 12-pulse converter will eliminate the 5^{th} and 7^{th} harmonics, which normally are the largest, under all operating conditions.

A way to reduce the harmonic currents on the line side even more is to split the converter into four converters operating 15° phase displaced with respect to each other. Such a 24-pulse converter will eliminate the 5^{th} & 7^{th}, the 11^{th} & 13^{th} and the 17^{th}&19^{th} harmonics.

Another way of reducing the harmonic currents injected into the supply network and at the same time reducing the input kVAR, is to add tuned filters at the input of the drive.

7 Connection configurations

The MEGADRIVE-LCI frequency converters described in this document are available in the following standard configurations:

- 6/6-pulse connection (... 0606 types), figure 8
- 12/12-pulse series connection (... 1212 types), figure 9
- Two-channel 12/12-pulse parallel connection (...2*06 types), figure 10

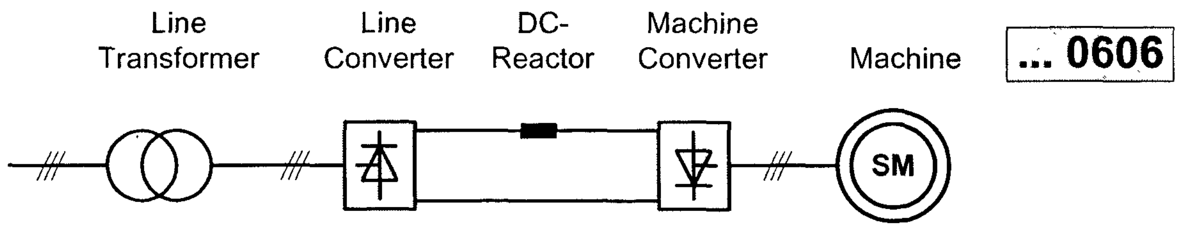


Fig. 8: 6/6-pulse

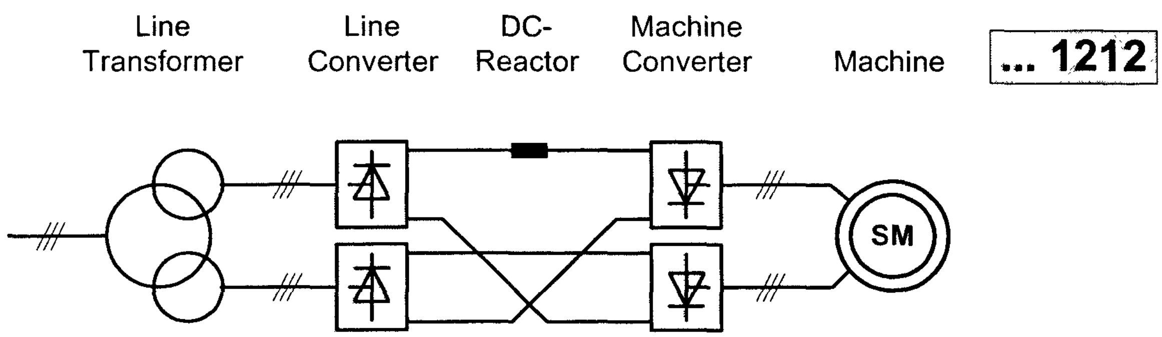


Fig. 9: 12/12-pulse

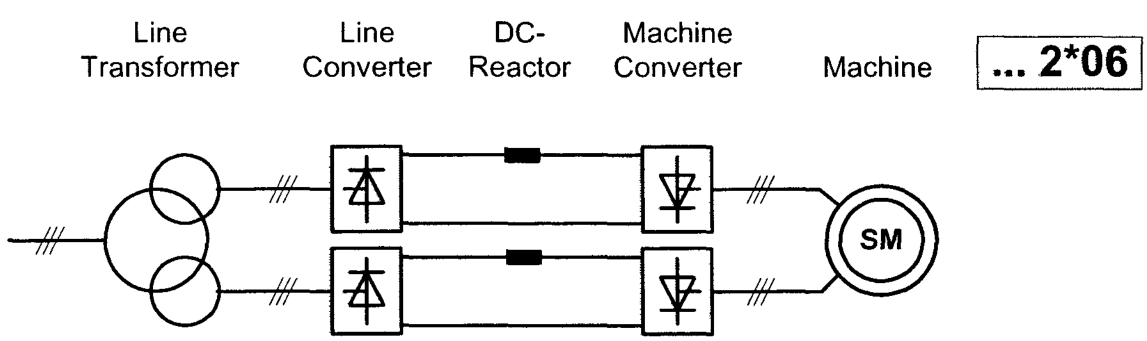


Fig. 10: Two-channel 12/12-pulse connection

The systems with 12/12-pulse connections (figure 9 and figure 10) include three-winding transformers with two secondary windings, phase-displaced by 30° el. and six-phase synchronous machines designed with two stator winding systems, each of which is fed by one 6-pulse converter.

Benefits from the 12/12-pulse configurations are less harmonic currents injected into the power supply, less harmonic heating of the motor and also reduced motor torque pulsations. The higher the drive power ratings are, the more important these features become. As a rule, the 12/12-pulse configuration is chosen for drive power ratings above about 4 MW.

When planning a drive, the connection configuration best suited to the particular application has to be selected. To this end, the features of the different configurations have to be brought into line with the requirements of the application, whereby the most important aspects are:

- Short circuit capacity of and impact of current harmonics upon the supply system.
- Additional heating of the motor as a result of current harmonics.
- Motor torque pulsations and their impact on the combined mechanical system comprising motor, shaft train and driven machine.
- Most economical splitting of the drive horsepower into converter voltage and current.

Additional, special but non-standard connection configurations are built by ABB on request, e.g.

- 24/12-pulse series connection (... 2412 types), figure 11

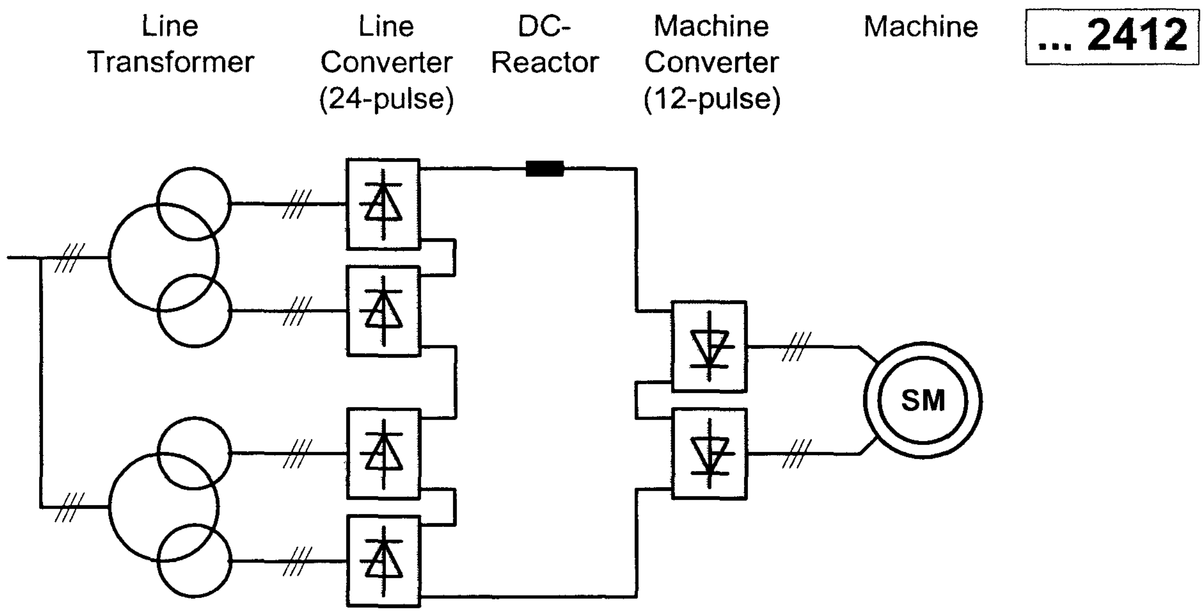
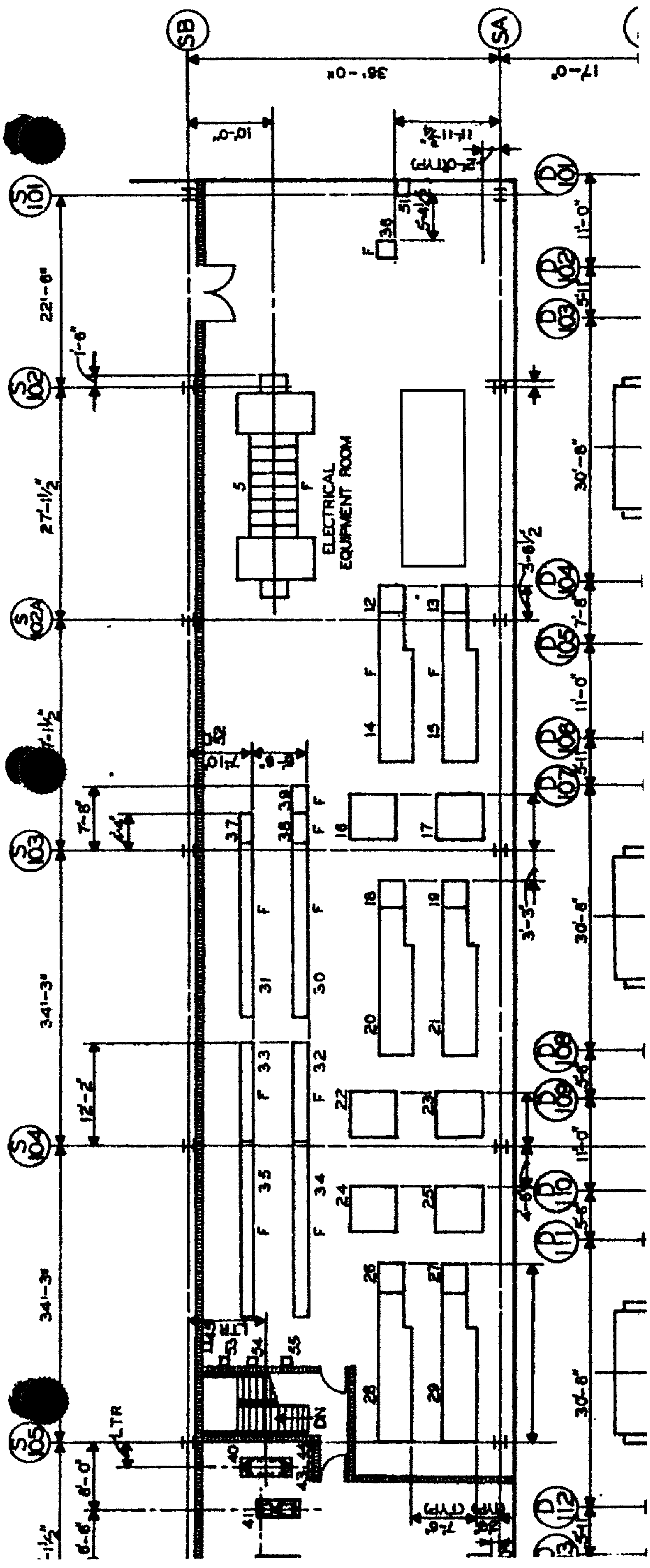
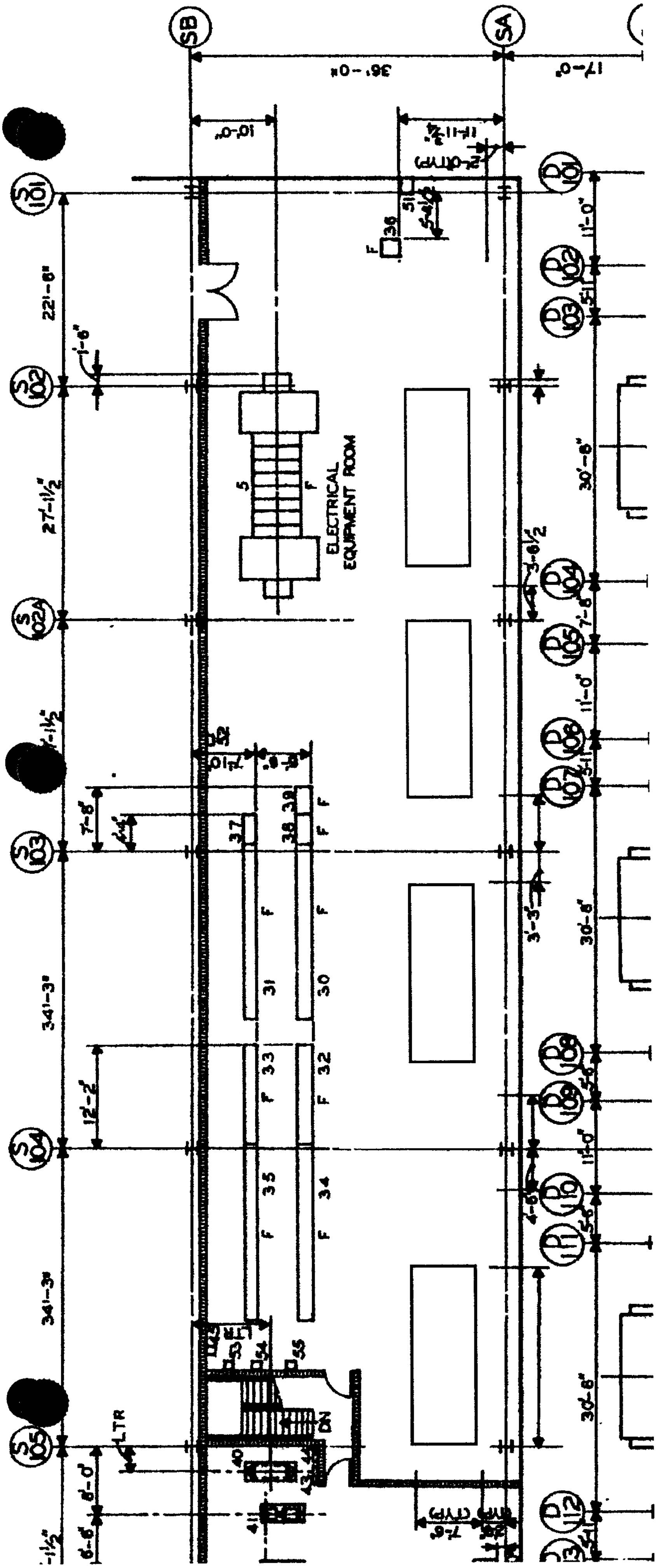


Fig. 11: 24/12-pulse series connection (... 2412 type)

The system with 24/12-pulse connection (Figure 11) includes two three-winding transformers with total four secondary windings, phase-displaced by 15° el. and a six-phase synchronous motor designed with two stator winding systems, each of which is fed by one 6-pulse converter.

Benefits from the 24/12-pulse configuration are less harmonic currents injected into the power supply, less harmonic heating of the motor and also reduced motor torque pulsations.


ELECTRICAL
EQUIPMENT ROOM


SB
SA
36'-0"
17'-0"
10'-0"
ELECTRICAL
EQUIPMENT ROOM
22'-8"
27'-1 1/2"
34'-3"
12'-2"
7'-8"
30'-8"
11'-0"
LTR
DN

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Project No.:	Delivery of 1st Unit	Project:	INTERMOUNTAIN SERVICE CORP. UTAH (USA)
Customer Ref. No.:			
Order intake date:	9/26/2003		
Delivery date:	2/20/2004	PM:	Date: 1/9/03 Visum:
Converter Serial No.			

Title: **Engineering, Manuf Testing Schedule**

2003

Item	Action Item	Responsible	Color	Start Date	End Date
	LCI.DR A1212-404R452 Converter				
10	Project Internal Kick off	Project Manager	rt	29/09/03	29/09/03
20	Clarify Open Items with Client (at Kick Off)	Project Manager	rt	29/09/03	06/10/03
30	Construction Details Converter	System Dimensioning	bl	29/09/03	03/10/03
40	Electr. eng./ Hardware diagram; Parts list for mech. Eng.	Electrical Engineering	bl	29/09/03	13/10/03
41	Electr. eng./ Work Shop Drawings	Electrical Engineering	bl	13/10/03	03/11/03
42	Electr. eng./ SW; Parameters, Testdocuments	Electrical Engineering	bl	03/11/03	16/12/03
50	Mech. Eng./ Parts list	Mechanical Engineering	bl	29/09/03	06/10/03
51	Mech. Eng./ Work Shop Drawings	Mechanical Engineering	bl	06/10/03	31/10/03
70	Purchasing of Material	Production	gr	06/10/03	24/11/03
80	Material of Subsuppliers Ready Deadline	Production	gr	25/11/03	01/12/03
90	Converter Assembling	Production	gr	01/12/03	12/01/04
100	Converter Testing	Test Field	gr	13/01/04	27/01/04
110	Customer Witness test (Optional)	Test Field	gr	28/01/04	28/01/04
120	Dismantling	Production	gr	29/01/04	29/01/04
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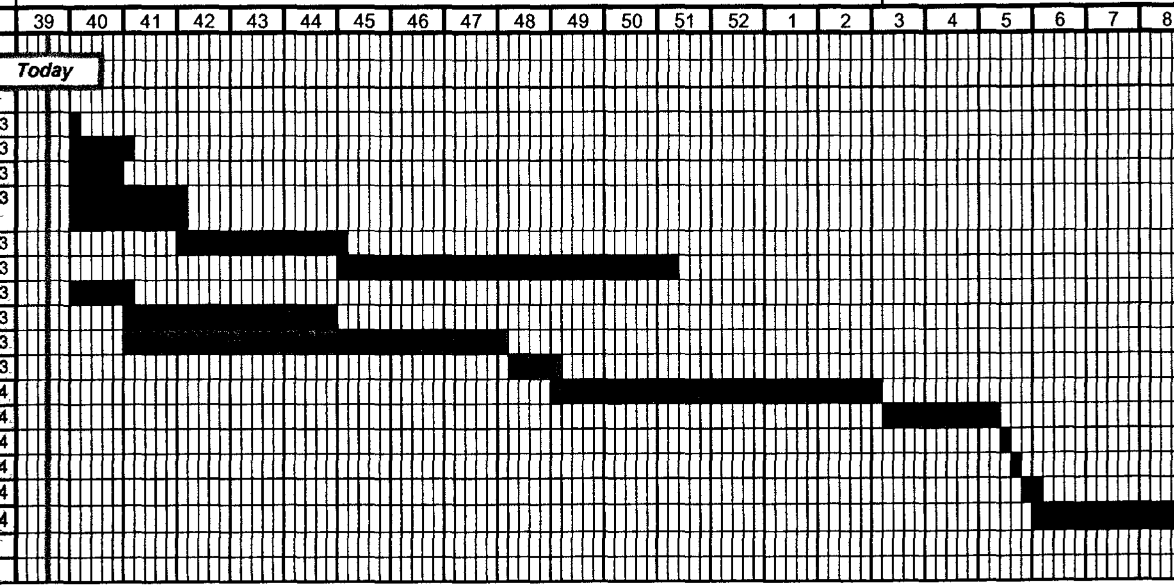
140	Delivery DDU Utah	Commercial Services	rt	02/02/04	20/02/04



Preliminary Harmonic Analysis

Project: Intermountain Power Service Corp.
ID Fan

Product: MEGADRIVE - LCI.DR

ABB-Tender No.: ATDA 3082202

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Prep Daniel Sax 03-08-28	Intermountain Harmonic Distortion Rev. A: 03-09-05, Sax				No of sh 6
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1. Summary

For the Induced Draft (ID) Fan Medium Voltage Frequency Drive (VFD) Systems the harmonic distortion has been calculated for the point of common coupling (PCC) on the 6.9 kV supply system and compared with the limits specified in the IEEE Std 519-1992. For this paper, three specific operating points within the speed range have been analysed and the typical harmonic distortion evaluated.

2. System Configuration

The following system characteristics have been considered:

Supply system data

- Voltage U_L = 6.9 kV ± 10%
- Frequency f_L = 60 Hz
- Fault level on 26 kV: S_C = 3300 MVA
- Fault level on 6.9 kV: S_C = 273 MVA
- VFD apparent power S_{VFD} (fund.) = 2 * 3380 kVA
- The supply system is supposed to be purely inductive; no cables, capacitor banks or other installations are considered.

Figure 1

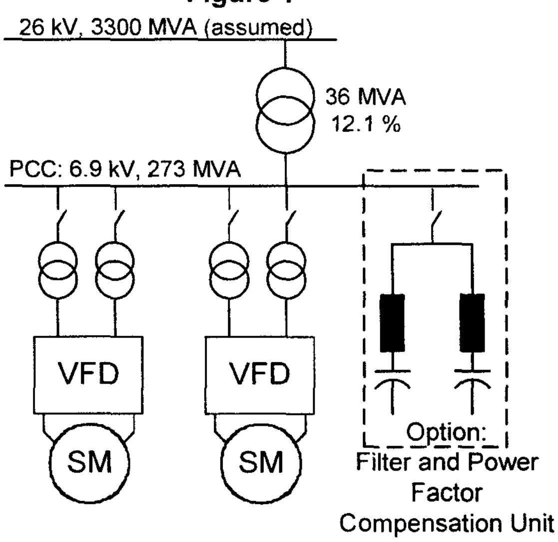

Table 1: Typical load points for one VFD

operating point		1	2	3	4	5	
VFD shaft power	P_{VFD}	691	1955	3591	4333	5529	[kW]
load (torque)	T	25	50	75	85	100	[%]
speed	n	477	675	826	880	954	[rpm]
VFD fund. current on 6.9 kV	$I_{C,1}$	140.4	274.7	413.7	473.1	565.3	[A]
demand load current on 6.9 kV	I_L	3000	3000	3000	3000	3000	[A]
rated voltage of supply system	U_L	6.9	6.9	6.9	6.9	6.9	[kV]

2. Harmonics of 12-pulse Operation

In the tables 2 to 6, the characteristic harmonic orders of a pure 12-pulse system and the noncharacteristic 6-pulse harmonics are listed.

Note: The noncharacteristic harmonics of the order 5, 7, 17, 19, etc. are given with 10 per cent of their value at 6-pulse operation, which considers non-symmetries of components and control.

Non-integer harmonics have been neglected (very low values, subject to specific analysis if necessary).

Tables 2 to 6 use the titles A, B, C and D which mean:

A calculated current harmonics i(h,calc) and TDD(calc) [%]

Note: 100% is corresponding to the demand load current I_L = 3000 A which results from the 36 MVA winding on 6.9 kV.

B max. admissible current harmonics i(h,adm) and TDD(adm) [%]
according to the IEEE Std 519-1992, Table 10.3 ($I_{SC} / I_L \Rightarrow < 20$)

Note: The IEEE Std 519-1992 refers the max. admissible harmonic current distortion to the *maximum demand load current I_L of the corresponding supply system.*

The IEEE Std 519-1992 allows to increase the limits of the characteristic harmonic orders by a factor equal to √2 (for 12-pulse operation) provided that the amplitudes of the noncharacteristic harmonic orders are less than 25 per cent of the limits specified in the tables.

C calculated voltage harmonics u(h,calc) and THD(calc) [%]
100% is corresponding to rated supply voltage (6.9 kV).

D max. admissible voltage harmonics u(h,adm) and THD(adm) [%]
according to the IEEE Std 519-1992, Table 11.1.

Note: Values in brackets exceed the limits according to the IEEE Std 519-1992.

Table 2: Distortion on 6.9 kV level with two VFDs at operating point 1

harmonic order	A	B	C	D	
5	0.36	0.25* 4.0	0.24	3.0	
7	0.13	0.25* 4.0	0.12	3.0	
11	0.85	√2 * 2.0	1.23	3.0	
13	0.72	√2 * 2.0	1.23	3.0	
17	0.05	0.25 * 1.5	0.12	3.0	
19	0.05	0.25 * 1.5	0.12	3.0	
23	0.40	√2 * 0.6	1.22	3.0	
25	0.37	√2 * 0.6	1.22	3.0	
29	0.03	0.25 * 0.6	0.12	3.0	
31	0.03	0.25 * 0.6	0.12	3.0	
35	0.26	√2 * 0.3	1.21	3.0	
37	0.25	√2 * 0.3	1.21	3.0	
41	0.02	0.25 * 0.3	0.12	3.0	
43	0.02	0.25 * 0.3	0.12	3.0	
47	0.19	√2 * 0.3	1.19	3.0	
49	0.19	√2 * 0.3	1.19	3.0	
TDD	**1.38**	**5.0**	**3.45**	**5.0**	**THD**

Table 3: Distortion on 6.9 kV level with two VFDs at operating point 2

harmonic order	A	B	C	D	
5	0.50	0.25* 4.0	0.33	3.0	
7	0.26	0.25* 4.0	0.24	3.0	
11	1.65	√2 * 2.0	2.39	3.0	
13	1.39	√2 * 2.0	2.38	3.0	
17	0.11	0.25 * 1.5	0.24	3.0	
19	0.09	0.25 * 1.5	0.23	3.0	
23	0.77	√2 * 0.6	2.32	3.0	
25	0.70	√2 * 0.6	2.30	3.0	
29	0.06	0.25 * 0.6	0.23	3.0	
31	0.06	0.25 * 0.6	0.23	3.0	
35	(0.48)	√2 * 0.3	2.21	3.0	
37	(0.45)	√2 * 0.3	2.19	3.0	
41	0.04	0.25 * 0.3	0.21	3.0	
43	0.04	0.25 * 0.3	0.21	3.0	
47	0.33	√2 * 0.3	2.06	3.0	
49	0.32	√2 * 0.3	2.03	3.0	
TDD	**2.60**	**5.0**	**(6.37)**	**5.0**	**THD**

Table 4: Distortion on 6.9 kV level with two VFDs at operating point 3

harmonic order	A	B	C	D	
5	0.65	0.25* 4.0	0.43	3.0	
7	0.39	0.25* 4.0	0.36	3.0	
11	2.44	√2 * 2.0	(3.52)	3.0	
13	2.04	√2 * 2.0	(3.48)	3.0	
17	0.15	0.25 * 1.5	0.34	3.0	
19	0.13	0.25 * 1.5	0.33	3.0	
23	(1.06)	√2 * 0.6	(3.19)	3.0	
25	(0.95)	√2 * 0.6	(3.12)	3.0	
29	0.08	0.25 * 0.6	0.30	3.0	
31	0.07	0.25 * 0.6	0.29	3.0	
35	(0.58)	√2 * 0.3	2.67	3.0	
37	(0.53)	√2 * 0.3	2.57	3.0	
41	0.04	0.25 * 0.3	0.24	3.0	
43	0.04	0.25 * 0.3	0.22	3.0	
47	0.33	√2 * 0.3	2.02	3.0	
49	0.30	√2 * 0.3	1.91	3.0	
TDD	**3.68**	**5.0**	**(8.16)**	**5.0**	**THD**

Table 5: Distortion on 6.9 kV level with two VFDs at operating point 4

harmonic order	A	B	C	D	
5	0.72	0.25* 4.0	0.47	3.0	
7	0.44	0.25* 4.0	0.41	3.0	
11	2.74	√2 * 2.0	(3.96)	3.0	
13	2.28	√2 * 2.0	(3.89)	3.0	
17	0.17	0.25 * 1.5	0.37	3.0	
19	0.14	0.25 * 1.5	0.36	3.0	
23	(1.12)	√2 * 0.6	(3.37)	3.0	
25	(0.99)	√2 * 0.6	(3.24)	3.0	
29	0.08	0.25 * 0.6	0.30	3.0	
31	0.07	0.25 * 0.6	0.28	3.0	
35	(0.54)	√2 * 0.3	2.49	3.0	
37	(0.48)	√2 * 0.3	2.32	3.0	
41	0.04	0.25 * 0.3	0.20	3.0	
43	0.03	0.25 * 0.3	0.18	3.0	
47	0.24	√2 * 0.3	1.47	3.0	
49	0.20	√2 * 0.3	1.31	3.0	
TDD	**4.04**	**5.0**	**(8.30)**	**5.0**	**THD**

Table 6: Distortion on 6.9 kV level with two VFDs at operating point 5

harmonic order	A	B	C	D	
5	0.82	0.25* 4.0	0.54	3.0	
7	0.52	0.25* 4.0	0.48	3.0	
11	(3.11)	√2 * 2.0	(4.49)	3.0	
13	2.53	√2 * 2.0	(4.32)	3.0	
17	0.17	0.25 * 1.5	0.39	3.0	
19	0.15	0.25 * 1.5	0.37	3.0	
23	(1.04)	√2 * 0.6	(3.13)	3.0	
25	(0.87)	√2 * 0.6	2.85	3.0	
29	0.06	0.25 * 0.6	0.23	3.0	
31	0.05	0.25 * 0.6	0.20	3.0	
35	0.30	√2 * 0.3	1.40	3.0	
37	0.23	√2 * 0.3	1.12	3.0	
41	0.01	0.25 * 0.3	0.06	3.0	
43	0.01	0.25 * 0.3	0.04	3.0	
47	0.04	√2 * 0.3	0.24	3.0	
49	0.06	√2 * 0.3	0.38	3.0	
TDD	**4.36**	**5.0**	**(7.82)**	**5.0**	**THD**

Appendix: Recommended Spare Parts for LCI.DR

C: Commissioning Spares
N: Normal 2-5 years Operation

Project: Intermountain Service Corporation

Recommended Spare Part List
(C: for commissioning; N: for normal operation (2-5 years))

Part Typ	Part Description	m = modified		BR1-A1212-604R452	BR1-A1212-604R452	
				C	N	
Control						
MPS 10/5-230/24/48	Power Pack 100-240Vac/dc//24/48Vdc/250W			1	1	
AF C094 AE02	Operation Panel	m		1	1	
AR C093 AE01	Output Relais 16 Fold			1	1	
CS A463 AE01	Supervision Analog	m		1	1	
CS A464 AE01	Supervision SR-SYMO	m		1	1	
FM 9925 AE1	Angle Shifter			1	1	
GD 9924 BE V2	SRM Trigger Unit			1	1	
GD B021 BE01	Gate Control Unit			1	1	
GD C780 BE21	B448 Interface to LINT/PINT			1	1	
HZ C075 A	Fan Tier 24V DC			1	1	
NU 8976 A99	Power Pack			1	1	
PM A324 BE01	Master-AZP			1	1	
PP C322 BE01	PSR2 Processing Unit	m		1	1	
SA 9923 AE01	Reference Voltage Generator	m		1	1	
UA C395 AE01	PT100-Monitoring					
UA C096 AE01	Analoge I/O (arc)			1	1	
UA C317 AE01	Measuring Device 1	m		1	1	
UA C318 AE	Measuring Device 2	m		1	0	
UA C326 AE01	Combi I/O			1	1	
UF C092 BE01	Binary Input 16 Fold			1	1	
UP C090 AE01	Binary Field Bus Coupler			1	1	
	Set of MCBs, Breakers				1	
	Set of small mech. parts			1		
Power Part						
DD C330 BE04	MV-LINT (ns=4,5,6)			1	1	
XV C517 AE10	MV-GDR (no BOD)			1	2	
	Thyristor 5.2 kV, 5STP 3452N0019			2	8	
	Snubber Resistor				2	
B25835-S2205-K7	Capacitor 2uF; +/-10%; 3.1kV				2	
1BK/300	Fuse; 6kV / 32A			2	3	
POLIM-C 6 0	Overvoltage Limiter; 6kV			2	3	
	Thyristor changing tool (air cooled conv.)			1	1	
Excitation / AC-controller						
	Contactor					
	Fuses			4	4	
	AC-controller				1	
Air Cooled Converters						
	Converter Fan				0	
	DC-Reactor Fan				0	
ES2-S	Diff. Pressure Switch, 0.2-2mbar; 250V/1A				1	
Total costs						

LABOR RATES

Date: March 14, 2003

The following stated labor rates are applicable during the Primary Working Hours (PWH) defined as 8:00 AM to 5:00 PM Monday through Friday, excluding all nationally recognized holidays.

	Base Rate
Field Service Representative	**$164.00 per hour**

Conditions of service:

- *Charges include time spent at the client's facility, travel round trip, and time spent preparing written reports.*
- *Travel charged at 48 cents/mile, or actual public transportation costs plus 10%.*
- *Living expenses charged at actual costs incurred plus 10%.*
- *Minimum four (4) hour charge for any call to a client's facility.*
- *All work over 8 hours in one day invoiced at 1.5 times the base hourly rate.*
- *All work performed on Saturday invoiced at 1.5 times the base hourly rate.*
- *All work performed on Sunday invoiced at 2 times the base hourly rate.*
- *All work performed on nationally recognized holidays invoiced at 3 times the base hourly rate.*
- *ABB Automation Inc. General Terms and Conditions apply.*
- *All parts used in repair invoiced separately.*

INBETRIEBSETZUNGS-ABLAUF
COMMISSIONING PROCEDURE

LCI.DR

Anlage/Kennwort:	Plant/Project Name:
ABB Bestell-Nr.:	ABB Order No.:
Kunde:	Customer:
Umrichter Typ:	Converter Type:
Block Nr.:	Block No.:

Contents

Commissioning procedure of a LCI (Load Commuteted Inverter) drive

This document describes generally the commissioning (work and time sequence) of the scope of supply of ABB Industrie. It indicates clearly:

a) commissioning work that will be done by ABB Industrie commissioning engineers.
b) prerequisites (installation, cabling and commissioning work) that have to finished (done and checked) by others (not by ABB Industrie commissioning engineers).

1. CONVERTER COMMISSIONING WITHOUT MOTOR

1.1 Prerequisites for beginning of commissioning (by others)

1.1.1 The following components must be installed:
- transformer
- converter
- reactor

1.1.2 The following power- and control-cabling must be concluded and checked:
- between the components in 1.1.1
- between the components in 1.1.1 and
  . the HV-breaker
  . the low voltage supply
  . the remote control

For HV-cables, a test report must be available (HV-test of cable including cable ends; each phase against ground and phase to phase).

1.1.3 The following components must be commissioned and ready for
- energizing the components in 1.1.1
  . the HV-breaker
  . the low voltage supply
- controlling the components in 1.1.1
  . the remote control

1.1.4 For converters with water cooling:
- the raw water circuit of the converter must be connected, checked and commissioned
- dejonized water must be available for the converter-internal closed water-circuit (about 200 liters for each converter)

1.1.5 Safety measures must be taken against unintentional energizing of the feeder lines.

1.1.6 One set of operation and maintenance manual must be available at site.

1.1.7 One set of spare parts must be available at site.

1.2 Mechanical and visual inspection
(by ABB Industrie commissioning engineers)

1.2.1 Ensure that the prerequisites for beginning of commissioning (chapter 1.1) are fullfilled
1.2.2 Check for damages occured during transport or erection.
1.2.3 Check the wiring for
- completeness and correctness
- screening and earthing
- polarity
1.2.4 Check that all terminals are properly tightened.
1.2.5 Check that all openings for cables have been closed.

1.3 Performance check of components and interfaces
(by ABB-Industrie commissioning engineers)
1.3.1 Energize low voltage supply to the converter
- 3xU1 / ac; for excitation and auxiliaries
- 3xU2 / ac; for space heaters (if existing)
- U3 / dc; for control
1.3.2 Check in the converter
- auxiliary power distribution
- supply units for 24V; +/-15V;+48V
- sequence control
- closed loop control / gate control firing units / pulse stages
- protection / monitoring
- display units
- excitation
- converter cooling : Fill in the dejonized water into the internal cooling circuit
1.3.3 Check the interfaces from converter to
- HV-breaker
- transformer
- remote control

1.4 Operating of the converter without motor
(by ABB Industrie commissioning engineers)
1.4.1 Energize the transformer
- precommissioning with low voltage supply
. check phase sequence at converter input
- apply rated voltage
. check phase sequence at control electronic input
1.4.2 Energize the converter and reactor
- apply rated voltage (machine cables disconnected; no firing pulses) at rectifier SRN.
- apply short circuit in dc-link:
. check current control with nominal current
. check commutation in rectifier SRN
- apply short circuit at inverter output:
. check current control in pulse-mode-operation

2. DRIVE COMMISSIONING WITH MOTOR

2.1 Remarks for commissioning with motor

Depending of the conditions at site the commissioning can continue with one of the following steps (I,II or III) and must always end with step III:

step I : motor uncoupled
step II : motor coupled with load-machine; no load operation
step III : motor coupled with load-machine; operation with nominal load.

2.2 Prerequisites for commissioning with motor (by others)

2.2.1 For step I

. installation and erection of motor finished, motor uncoupled, motor ready to run
. cabling between motor and other components finished and checked (for HV-cabling a test report must be available)
. lube oil piping/cooling water piping established, checked and cleaned
. oil system: flushed and provided with definitive oil filling, emergency oil supply (changeover of main oil pump to emergency oil pump) tested and complete system ready for operation
. oil recooling-unit ready for operation
. water system: flushed and provided with definitive water filling
. complete system ready for operation
. water recooling-unit ready for operation
. converter commissioning finished, converter ready for operation.

2.2.2 Additional for step II

. motor coupled with load machine (the final alignement report must be available)
. auxiliaries of load machine installed, checked, commissioned and ready for operation
. motor and load machine ready to run

2.2.3 Additional for step III

. process or simulation of process ready to run the load machine with load up to nominal load.

2.3 Mechanical and visual inspection (by ABB Industrie commissioning enginers)

2.3.1 Ensure that the prerequisites for commissioning with motor (chapter 2.2) are fulfilled

2.3.2 Check for damages occured during transport or erection

2.3.3 Check bearings after oil flushing

2.3.4 Commissioning of motor acc. "Instructions for installation operation and maintenance for variable speed synchronous motor and rotating exciter", chapter 5 "Commissioning and operation"

2.3.5 Check the wiring for
- completeness and correctness
- screening and earthing
- polarity

2.4 Performance check of components and interfaces (by ABB Industrie commissioning engineers)

2.4.1 Check the interfaces from motor to
- converter
- other components (if existing)

2.4.2 Check in the converter
- all units having interfaces to the motor, e.q.
  . speed monitoring
  . temperature and vibration monitoring
  . contact monitoring

2.5 Operation with running motor

2.5.1 Before start-up
- check lube oil flow
- check cooling water flow

2.5.2 Check excitation system

2.5.3 Check reference voltage for machine-side-converter SRM for puls-mode operation

2.5.4 Check puls-mode-operation from speed 0 until about 10% of nominal speed

2.5.5 Check direction of rotation of motor (during first start-up)

2.5.6 Check reference voltage for machine-side-converter SRM for machine-commutated-operation

2.5.7 Check machine-commutated-operation from about 10% until 100% of nominal speed
Items to be checked and optimized over the whole speed range (definitive settings only possible with nominal load):
- current control
- machine voltage control
- speed control
- firing angle and commutation of machine-side-converter SRM

3. FINAL WORKS

- check that spare parts are complete and functional
- check whether schematics have been modified clearly to changes made during commissioning.

4. TIME FRAME

The expected time for commissioning is approximately:

Part 1:	2 Weeks
Part 2:	1 Week
Part 3:	2 Days

ABB		Code:
Text:	Document no:	ABB Switzerland Ltd / Switzerland

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MV Drives

Division ATD

Drives

Preservation, Storage, Commissioning Procedure, De-commissioning, Inspection, Repair

Issued:			Change	Off. resp.: ADTE	Doc.-type	Language	Format	Page	No of pages
Check. 1:	-	A		Rec. off.	UM	E	A4	1	19
Check. 2		B		Der. from:					
Released:		C		Replaces	ABB Switzerland Ltd / Switzerland				

Content

1. Preservation and Storage

1.1 Storage Conditions

The minimum requirements for storage are defined on the basis of IEC 721-3-1 'Classification of environmental conditions; Part 3: Classification of groups of environmental parameters and their severities; Storage'.

Classification:	1K2 */ 1B1 / 1C1 / 1S1 / 1M1
Storage time:	1 year
Microclimatic class:	X2 / Y1

* max. allowed temperature: +55°C

Pay attention to always fulfill the following environmental conditions during the storage period:

Air temperature:	+5 ... +55°C
Relative air humidity:	5% ... 85%

1.1.1 Preservation

Take the following measures, if you want to store the converter module for one year. In case of a longer storage period contact ABB service organisation.

1. Install and fix the converter on a wooden frame or palette.
2. Cover all cable and air inlets and outlets with a wooden plate. Insert an impermeable plastic or aluminum foil between the cover and the opening.
3. Add the desiccant of the appropriate quality: 1 unit desiccant (30g) absorbing 6g water vapor. You need the following quantity with respect to the packaging material:
   - PE foil: 10 units/sqm foil
   - ALU foil: 8 units/sqm foil
4. Close the doors and lock them.
5. Use polyethylene or aluminum-combination foil as humidity barrier of the following quality:
   - PE foil: 0,3g/sqm/24h water vapor diffusion
   - ALU foil: 0,01g/sqm/24h water vapor diffusion
6. Add humidity indicators (e.g. mechanical hygrometers) within the packaging. Place them on the converter front doors for example.

1.1.2 Periodical Inspections

During the storage period you should control the storage conditions and the condition of the converter every month. For this reason check the condition of the packaging. *Pay attention to damages caused by mechanical forces, water/humidity and heat/fire.*

If the *packaging is damaged* or you find damages caused by *water/humidity* or heat/fire you have to unpack the converter and to check its condition outside and inside (see sub-paragraph 2.4.4). Before storing the converter once again all damages have to be removed. Preserve the converter as described above under paragraph 3.4.

2. Erection

2.1 Preparatory Works

2.1.1 Foundation

The foundation for the converter has to be prepared as follows:

- horizontally adjusted +/- 0,5 %
- load capacity corresponding to the weight of the converter module
- non-abrasive
- protected against humidity diffusion

Note: For defining the exact location of the foundation and the minimum distances refer to the installation plan.

2.1.2 Cable Compartment

The cable compartment has to be prepared as follows:

- non-abrasive
- protected against humidity, dust and entrance of animals
- protected against fire extension

! **Important:** All openings have to be well covered/sealed to prevent possible fire from extending into the converter.

2.1.3 Converter Installation

Follow the instructions below to erect the converter module. Be sure you have the 'User's Manual' Part 4 with you.

! **Important:** Be sure that all cable and air inlets / outlets are protected against the entrance of dust, humidity and animals.

1. Place the converter exactly on the prepared foundation and tighten all fixing screws.
2. If necessary support the converter with leveling shims.
3. Mark the location of the cable glands on the bottom shield. Be sure the cable glands diameter exactly fits the cable diameters.

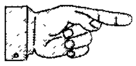
4. Remove the bottom shield, prepare the cable glands openings and mount the cable glands.

! **Important:** Be sure that there is no mechanical stress acting on the cables and the cable terminals.

! **Important:** Observe the different torques for power cable connections as set out below(specification of screws: ST-NR A2-70)

Size	M10	M12	M16	M20	M24
Torque [Nm]	19.0	31.0	76.0	153.0	147.0

! **Important:** Pay attention to correct power and signal cable placing in order to prevent interferences.



Notice !

Never use blank aluminum cable lugs in combination with copper bars !
This material mix could cause corrosion and damage the converter !
Use nickel-plated aluminum or copper cable lugs !

5. Always use the cable quality as described here.

   a) HV and LV cables:
   - temperature range from -55°C to +120°C
   - halogen-free
   - flame retardent
   - cable cross section according to the operating current and installation conditions
   - shielded cables for signal and control connections

   b) Grounding cables/bars:
   - cross section min. 2 x 150 sq millimeters

   c) Insulation level of all cables according applied voltages and regulations.

6. Fix the bottom shield and pull the cables through the cable glands. Tighten the gaskets.

7. Test the insulation (for all power and control cables) and fill out the test report (necessary for commissioning). The insulation tests have to be performed with the following test voltages (IEC 146-1-1):

   Test Voltage / Low Voltage

$U_M / \sqrt{2}$	**Test Voltage**
≤ 60 V	500 V
≤ 125 V	1000 V
≤ 250 V	1500 V
≤ 500 V	2000 V

Test Voltage / Medium Voltage

Line Voltage [kV]	Impulse Voltage [kV peak] (1,2 µs / 50 µs)	AC Voltage [kV rms] (power frequency)
$0,5 < U_{LN} \leq 1,1$	not applicable	1 + 2 UM / √2
$1,1 < U_{LN} \leq 3,6$	not applicable	1 + 3 UM / √2
$3,6 < U_{LN} \leq 38$	15 + 3 UM / √2	1 + 1,8 UM / √2

8. Connect the power and earthing cables/bars according to the interface diagram..

9. Connect all control and signal (low voltage) cables according to the interface diagram. Be sure all contact surfaces are cleaned immediately before mounting the cables (if necessary: use a steel brush to remove oxidation layers).

2.1.4 Final Control

1. Check all cable connections (position and torques).
2. Check the correct mounting and position of all cable shields.
3. Check the gaskets at the cable glands.
4. Check that the cooling air inlets and outlets are properly installed.
5. Check the grounding cables/bars.
6. Check that the information plates, safety signs and protection shields are located at the right position inside and outside the converter module.
7. Check position and fixing of all HV protection shields inside the converter block.
8. Do not forget to take all tools and materials with you when you leave the converter site.

! **Important:** Do not hesitate to inform the local ABB service organisation about problems and difficulties during erection work.

3. Commissioning

3.1 Converter Commissioning Phase 1 (Motor Disconnected)

3.1.1 Preconditions

Be sure to fulfill the following preconditions before the ABB commissioning team starts to work on the converter.

1. The following system components must be erected and installed:
   - transformers;
   - converter module.

2. All main and low voltage power supplies have to be connected.

3. The following power and control cable connections are checked:
   - between converter and transformer;
   - between converter and AC/DC low voltage supply;
   - between converter and remote control system

! **Important:** Do not forget to check the HV cable test report with regard to insulation values and test voltage.

4. The high and low voltage supplies and the remote control system must be ready for operation.

5. One set of the recommended spare parts and of the earthing cables must be available on site.

6. One complete set of the 'User's Manual' must be available on site.

3.1.2 Mechanical and Visual Inspection

! **Important:** Be sure the preconditions (see sub-paragraph 5.3.1) have been fulfilled.

1. Check the condition of the converter with regard to transport or erection damages.
2. Check the external cable connections according the converter interface diagram and the erection instructions with regard to
   - position;
   - shielding incl. earthing;
   - earthing;
   - polarity.
3. Check that all terminals are properly tightened, completely and properly mounted.
4. Check that the space between the cable bundles and the cable glands is well sealed.

3.1.3 Performance Check

1. Energize the low voltage supply to the converter as follows:
   - 3x600 V AC (excitation and auxiliaries)
   - 2x120 V AC (control system)
   - 1x208 V AC (light and heating)
2. Now check the following converter features:
   - low voltage power distribution;
   - supply units for 24 V / +/- 15 V / 48 V;
   - sequence control;
   - closed loop control / gate control unit / pulse stages;
   - protection and monitoring;
   - control and monitoring indications;
   - excitation;
   - cooling system.
3. Check the interface between the converter and the
   - transformers;
   - remote control system.
4. Check the circuit breaker control or feedback:
   - test position: On/Off sequences and feed back signals

3.1.4 Operation Check with High Voltage Applied

1. Put the circuit breaker in its test position, connect to earth, create a short-circuit at the inverter output and disconnect from earth.

2. Put the circuit breaker in its service position and close it.

3. Energize the transformer as follows (firing pulses of the converter blocked):
   - supply rated voltage;
   - check phase sequence at the line side gate control unit GD B021 (+BPA10).

4. Energize the rectifier, the DC reactor and the inverter (motor disconnected) *while inverter output short-circuited* as follows:
   - energize the converter by releasing the pulses;
   - check current control in pulse mode operation;
   - disconnect the converter from the rated voltage by opening the circuit breaker.

5. Put the circuit breaker in its test position, connect to earth, disconnect the short-circuit at the inverter output and disconnect from earth.

4. Converter Commissioning Phase 2 (Motor Connected)

4.1.1 Preconditions

Be sure to fulfill the following preconditions before the ABB commissioning team starts to work on the converter.

1. The erection and installation of the motor has to be finished. The motor has to be coupled and ready for operation.

2. The cable connections between the motor and the converter are checked.

! **Important:** Do not forget to check the HV cable test report with regard to insulation values and test voltage.

4.1.2 Mechanical and Visual Inspection

! **Important:** Be sure the preconditions (see sub-paragraph 5.3.1 and 5.4.1) have been fulfilled.

1. Check the condition of the converter with regard to transport or erection damages.

2. Check the external cable connections according the converter interface diagram and the erection instructions with regard to
   - position;
   - shielding incl. earthing;
   - earthing;
   - polarity.

3. Check that all terminals are properly tightened, completely and properly mounted.

4. Check that the space between the cable bundles and the cable glands is well sealed.

4.1.3 Performance Check

Check the motor/converter interface: HV cables and excitation cables connected properly according to the interface diagram.

4.1.4 Operation Check

! **Important:** Before starting the motor has to be ready for rotation.

1. Switch on the low voltage power and the main power supply.
2. Check the low voltage distribution and the excitation system.
3. Check reference voltage of inverter for pulse mode operation.
4. Check direction of rotation of motor (during first starts).
5. Check pulse mode operation.
6. Check reference voltage of inverter for machine (load) commutated operation.
7. Check machine commutated operation.
8. Optimize (if necessary) over the whole speed range:
   - DC current control loop;
   - motor voltage control loop and excitation current control loop;
   - speed control loop;
   - firing angle and inverter commutation.

4.1.5 Final Control

1. Check quality and quantity of the spare parts.
2. Test all replacement PCB's (spare parts) by replacing the original PCB's with the spare PCB's.
3. Clearly note all modifications made during commissioning in the hardware and software diagrams.
4. Send 1 copy of the modified diagrams to ABB Switzerland Ltd., Switzerland.

! **Important:** ABB Switzerland Ltd. will send the definite version of the modified hardware and software diagrams to the customer within one month after receiving the hand-modified diagrams.

5. Decommissioning

5.1 Converter Standstill

In case of a short time converter standstill (less than 6 months) please observe the following instruction in order to avoid damages.

!

Important: Pay attention to the preservation and storage instructions (see chapter 3 of this manual)

1. Disconnect all power supplies and connect to earth.
2. Put the circuit breaker in its test position.
3. Protect the converter against dust, humidity, dirt, and other detrimental influences.
4. Inspect periodically the condition of the converter module (see chapter 3.5 of this manual).

5.2 Converter Intermediate Storage

! **Important:** Before removing the external cable connections switch off all power supplies.

1. Disconnect all power supplies and connect to earth.
2. Put the circuit breaker in its test position.
3. Discharge the circuit breaker spring system.
4. Observe the following cable connection dismounting sequence:
   1. Mark all cable connections.
   2. Dismount the power cables.
   3. Dismount the control cables.
   4. Dismount the earthing cables/bars.
5. Refer to chapter 3 for all other storage measures.

5.3 Dismantling the Converter and Separation of Materials

Do not forget that used materials can serve as raw materials for another purpose. For environmentally compatible waste handling please contact your community or the local waste disposal company.

5.4 Disposal and Recycling

Contact your local authorities for more detailed information about disposal and recycling of materials and components. Note that the future quality of our environment depends on what we are doing today for environmental protection.

6. Converter and Circuit Breaker Spare Parts Replacement

6.1 Replacement of the Printed Circuit Boards (PCB)

Every printed circuit board (PCB) has a fault indication system (red LED on: fault / green LED on: working properly (optional)). Refer to the Hardware diagram for easily finding out the PCB that has to be replaced.

Follow these instructions to replace a PCB. *Be sure you have disconnected the main power supply and the auxiliary power supplies.*

1. Use a screw driver to loose the screws from the PCB.
2. Pull out the PCB by using the handles on the front plate. *Handle with care. Do not touch the printed circuits.*
3. If you change more than one PCB of the same size/type at the same time pay special attention to their original position.
4. Check if the following numbers of the original and the new PCB are identical:
   - type number (white number on the front plate of the PCB);
   - identification number (white label on the PCB; number beginning with 'H' followed by 3 letters plus 6 numbers and letter 'R' plus 1 to 4 numbers) or '3BHS' plus 6 numbers;
   - if you replace *modified print* check the modification number (red label).
5. Check if the *modifications (if there are any) of the original and the new PCB* are identical (if not, modify the new PCB identically as the original PCB.
6. Check if the dip switches and/or code switches (if there are any) of the original and the new PCB are in identical positions.
7. Replace the PCB and tighten the screws.
8. Switch on the auxiliary power supplies.

6.2 Replacement of Other Parts

For replacing other components, neither special tools, nor specific procedures are necessary. *Pay attention to the following aspects in order to avoid damages.*

1. Disconnect all power supplies *before* replacing a component.
2. Mark all electrical and mechanical connections *before* disassembly for proper installation of the spare part.
3. Always check if the type/identification/modification numbers or other identification devices (dip switches, code switches etc.) on the original and on the spare part are identical.

7. Inspection, Servicing and Repairs

7.1 Dealing with Troubles

If you have any problem during inspection, servicing or repair work the ABB Switzerland Ltd trouble shooting support is at your disposal. Please proceed along the following steps. *In any case of fault or malfunction please send form 1 (see paragraph 1.6 of this manual) to ABB Switzerland Ltd Switzerland.*

1. Do any inspection work with the help of this manual.

2. Ask your local ABB service organisation.

3. Ask ABB Switzerland Ltd Switzerland for on-line support by phone.
   (hotline: see paragraph 1.4 of this manual)

4. Ask ABB Switzerland Ltd Switzerland for support on site.

7.1.1 Inspection Program

Interval: Once a year
Responsible: ABB Switzerland Ltd or authorized service organization in cooperation with customer.

! Important: The converter is designed for operation under specific environmental conditions (see 'User's Manual' Part 2 sub-paragraph 2.3.2). If the actual environmental conditions differ from the defined conditions contact your local ABB service organisation.

! Important: Never change the sequence of inspection steps as set out below.

Step	What To Do	Remarks
1	**Visual and mechanical inspection**	STOP **High Voltage** ***Danger*** Follow the safety instructions as set out under 5.1
1.1	Remove all dust carefully by the use of a vacuum cleaner. Never use the vacuum cleaner for PCB's. *Note: PCB's handle with care.* Do not touch the printed circuits. Do not use a vacuum cleaner. Remove dust with a smooth paint brush.	**Notice** Never use hot steam, compressed air or chemical agents! This could cause a damage to the converter!
1.2	Check environmental conditions for operation, if you find - dust containing grease and/or metallic particles; - humidity. Remove all greasy, metallic dust and humidity immediately.	**Notice** Greasy dust, metallic particles and humidity could damage the converter! Adjust the environmental conditions! (ref. to the 'User's Manual Part 1 sub-paragraph 2.3.1)
1.3	Check fan filter in +BPA10 rack 'Fan'. Loosen the four outer screws, pull out the fan rack and dismount the filter holder. Blow out the dust if necessary. Replace the filter if dry cleaning is not sufficient.	**Notice** Never loosen the two inner screws for disassembling the fan rack.
1.4	Mechanical checks of isolator (+BPA70): - if the lubrication is inadequate or missing clean the areas concerned and regrease - top up the grease on all sliding and bearing surfaces	**Notice** Never use: - trichlorethane - trichlorethylene - carbon tetrachloride Use the following grease: Isoflex Topas NB 52
1.5	Check - tightness of all 'Faston' connections - tightness of all connections of terminal blocks	

Step	What To Do	Remarks
1.6	Check number and position of all safety instructions/signs mounted inside the converter and outside the converter block; replace the missing instructions/signs.	Ref. to diagram in the 'User's Manual' Part 4
1.7	Check position of protection shields against unintentional contact; replace the missing shields.	Ref. to diagram in the 'User's Manual' Part 4
2	**Mechanical check of the converter and the reactor fans (+BPA20/30)** **! Important :** Switch on the low voltage power supply for the mechanical checks.	STOP **High Voltage *Danger*** Follow the safety instructions as set out under 5.1
2.1	Pay attention to abnormal noise when the fans are running.	**Caution** Do not attempt to stop the rotating fan blades mechanically. *Note*: The fan has a run-out time of about 5 minutes.
2.2	In case of abnormal noise: a) disconnect HV supply b) connect to earth c) disconnect the low voltage power supply d) replace the fan	**Caution** Never try to rotate the fan manually. This could hurt you and cause a damage to the fan
3	**Functional checks** (part 1) **! Important :** Switch on the low voltage power supply for the functional checks.	STOP **High Voltage *Danger*** Follow the safety instructions as set out under 5.1
3.1	Test lamps at converter control panels; use the specific lamp test buttons.	
3.2	Test the differential pressure switch (+BPA20/30): activate the switch by sucking off the air; pay attention to the switching noise.	

Step	What To Do	Remarks
3.3	Test all trip conditions	
3.4	Test all interlocking conditions, pay attention to proper working of the micro switches at the high voltage compartment doors	
4	**Functional checks** (part 2) **! Important :** Switch on the low and high voltage power supplies for the functional checks.	 **High Voltage** ***Danger*** Follow the safety instructions as set out under 5.1
4.1	Start the converter by the remote control system.	
4.2	Check the start and stop sequences according to the 'User's Manual' Part 2 chapter 2.	

7.1.2 Servicing Program

The converter is maintenance-free. *Be sure to observe strictly the inspection program and intervals.*

ABB Industrie AG / SWITZERLAND

DIVISION IA

Drives and Power Electronics

INSPEKTIONS- UND PRUEFPLAN (ITP)
INSPECTION AND TEST PLAN (ITP)

Produkt: Product:	Luftgekühlter statischer Umrichter zu drehzahl-geregeltem Antrieb Air cooled static converter for variable speed drive system
Erfüllte QS-Norm: Performed QA standard:	ISO 9001

Auftragsbezogene Festlegungen
Order related commitments

Anlage:
Plant:

Kunde:
Customer:

Externe Bestell-Nr.:
External Order No.:

ABB-Bestell-Nr.:
ABB-Order No.:

BESCHREIBUNGEN / DESCRIPTIONS

1.0 Abkürzungen	**Abbreviations**
ITP = Inspektions- und Prüfplan	ITP = Inspection and test plan
WES = Wareneingangsschein	WES = Incoming inspection form
LP = Laufprüfliste	LP = Inspection tracer
TR = Prüfprotokoll	TR = Test report
LS = Lieferschein	LS = Delivery note
2.0 Definitionen	**Definitions**
2.1 Codes (Eintrag in Spalte 3)	Codes (entry in column 3)
1 Zulieferer	1 Sub-supplier
2 Wareneingang	2 Incoming inspection
3 Fertigungs- u. Montageprüfung	3 Manufacturing/assembling inspection
4 Endprüfung	4 Final test
5 Ablieferprüfung	5 Delivery inspection
6 Inbetriebsetzung	6 Commissioning
7 On site Prüfung	7 On site test
2.2 Haltepunkte	Hold Points
Prüfungs-/Abnahmebereitschaft mitteilen. **WARTEN** bis Teilnahme bzw. Mitteilung, dass auf Teilnahme verzichtet wird, schriftlich bestätigt ist.	Notify date of readiness for inspection or acceptance. **WAIT** for presence of witness respectively for notification that witnessing will be waivered.
Wichtig: Wartezeiten über den gemeldeten Bereitschaftstermin hinaus gehen zu Lasten des Kunden.	**Important:** Waiting times beyond notified date of readiness are for customers account.
H = Prüfteilnahme	H = Presence at inspection
2.3 Meldepunkte	Witness Points
Prüfungs-/Abnahmebereitschaft mitteilen. Teilnahme bzw. schriftliche Mitteilung, dass auf Teilnahme verzichtet wird, **NICHT ABWARTEN.**	Notify readiness for inspection or acceptance. **DO NOT WAIT** until test witnessed or visit cancelled in writing.
W = Prüfteilnahme	W = Presence at inspection

3.0 Allgemeine Festlegungen / General Commitments

3.1 Eintrag der Melde- und Haltepunkte

Alle geforderten Melde- und Haltepunkte sind vom Kunden bzw. dessen authorisiertem Vertreter in den Prüfplan, in Spalte 5 einzutragen.

Entry of witness- and hold points

All required witness-and hold points have to be entered into the inspection and test plan, in column 5 by the customer resp. its authorized deputy.

3.2 Genehmigung von Prüfplänen

Alle auftragsspezifischen Prüfpläne müssen vom Kunden bzw. dessen authorisiertem Vertreter genehmigt werden. Der Genehmigungsstatus muss eindeutig auf dem Deckblatt ersichtlich sein.
Es muss folgendes beinhalten:
- geprüft und freigegeben
- Datum
- Genehmigungsinstanz/Visum

Approval of inspection and test plans

All order-specific inspection and test plans must be approved by the customer resp. its authorized deputy. Approval status must be clearly visible on the cover sheet.
It must contain the following:
- checked and released
- date
- Approval authority/Signature

3.3 Anmeldung der Prüfbereitschaft

Bei allen im Prüfplan festgelegten Melde- und Haltepunkten ist durch den Projektleiter der Kunde bzw. dessen authorisierter Vertreter von der Prüfbereitschaft zu benachrichtigen.

Wurde auftragsspezifisch keine zeitliche Abmachung der Voranmeldung getroffen, gilt folgendes:

- Abnahmebereitschaft mindestens 10 Arbeitstage vorher anmelden

- Definitive Durchführung mind. 3 Arbeitstage vorher bestätigen

Notification of readiness for inspection

For all witness- and hold points specified in the inspection and test plan the customer resp. his authorized deputy has to be notified by the projectleader.

If no arrangement has specifically been made concerning notification with respect to time, following provision will hold good:
- notify readiness for acceptance at minimum 10 working days in advance
- definitve performance to be confirmed at min. 3 working days in advance

3.4 Verzicht auf Teilnahme von Melde- und Haltepunkten

Wird vom Kunden bzw. dessen authorisiertem Vertreter auf eine Prüfungsteilnahme bei festgelegten Melde- und Haltepunkten verzichtet, so hat er dies der zuständigen Verkaufs-

Cancellation of participation in witness- and hold points

If participation in comitted witness- and hold points is cancelled by customer resp. his authorized deputy, this must be notified in writing to the relevant sales departabteilung innerhalb ABB schriftlich mitzuteilen.

ment within ABB.

3.5 Inspektions- und Abnahmebestätigung

Inspection and Acceptance Confirmation

Nach erfolgreich durchgeführter Prüfung bestätigt der zuständige Kundeninspektor in der Spalte 7 im Prüfplan oder auf dem Prüfprotokoll seine Prüfungsteilnahme.

After inspection performed successfully the relevant inspector of customer confirm his inspection participation in column 7 in the inspection and test plan or on the test report.

3.6 Abgabe von Prüfnachweisen an den Kunden

Submission of Inspection certificates to the customer

Prüfnachweise dürfen grundsätzlich nur von der zuständigen Verkaufsabteilung an den Kunden abgegeben werden.
Dies hat nach den vertraglichen Festlegungen zu erfolgen. Der Kunde hat die von ihm geforderten Prüfnachweise im Prüfplan in Spalte 6 zu definieren.

Basically inspection certificates must be submitted to customer solely by the relevant sales department. This has to be established in accordance with the contractual stipulations. Customer has to specify inspection certificates required by him in the inspection and test plan in column 6.

Seite Nr. Page No.	Objekt Object	Wareneingang Goods receipt	Teilmontage Preassembly	Endmontage Final assembly	Endprüfung Final test	Spedition Shipping	Anlage On site
6	Normmaterial Standard material	1					
7	Drossel DC-Reactor				24		
8/9	Umrichter-Block kpl. Converter unit compl.			33	34		
10	Umrichter Anlage kpl. Converter plant compl					45	
11	System kpl. System compl.						56

TEIL Normmaterial
ITEM: Standardmaterial

Legende Legend:	1 = Prüf-Nr. test sequence No. 2 = Kundenref. Nr. customer ref. No.	3 = Prüfungsdurchführung test performed by 4 = Stand.-Bescheinigung standard certificate	5 = Halte u.Meldepunkte hold and witness points 6 = Nachweis f. Kunden Records for customer 7 = Visum Inspektor signature Inspector

1	2	Prüfpunkt/Merkmal Inspection point/ characteristic	Prüfung nach Inspection/test according to	3	4	5 H	 W	6	7
1		Bei der Warenannahme On the receipt of goods - Menge Quantity - Uebereinstimmung mit Bestellung Conformance with order - Aussehen Visual appearance - Beschädigungen Damages	Bestellung Order	2	WES	-	-	-	

TEIL Drossel
ITEM: DC-Reactor

Legende Legend:	1 = Prüf-Nr. test sequence No. 2 = Kundenref. Nr. customer ref. No.	3 = Prüfungsdurchführung test performed by 4 = Stand.-Bescheinigung standard certificate	5 = Halte u.Meldepunkte hold and witness points 6 = Nachweis f. Kunden Records for customer 7 = Visum Inspektor signature Inspector

1	2	Prüfpunkt/Merkmal Inspection point/ characteristic	Prüfung nach Inspection/test according to	3	4	5 H	 W	6	7
24		Beim Lieferanten At the supplier - Messung des Wicklungs-widerstandes Measurement of winding resistance - Messung der Induktivität Measurement of incremental inductance - Fremdspannungsprüfung Separate source voltage withstand test	- Bestellung Order - IEC 289	1	TR			TR	

TEIL
ITEM:

Umrichter-Block kpl.
Converter unit compl.

Legende
Legend:

1 = Prüf-Nr.
test sequence No.
2 = Kundenref. Nr.
customer ref. No.
3 = Prüfungsdurchführung
test performed by
4 = Stand.-Bescheinigung
standard certificate
5 = Halte u.Meldepunkte
hold and witness points
6 = Nachweis f. Kunden
Records for customer
7 = Visum Inspektor
signature Inspector

1	2	Prüfpunkt/Merkmal Inspection point/ characteristic	Prüfung nach Inspection/test according to	3	4	5 H	 W	6	7
33		Während und nach der Montage During and after assembly - Mechanische Funktionen Mechanical Functions - Güte der lösbaren und nicht lösbaren Verbindungen Quality of detachable and non detachable connections - Gesamter Aufbau Complete assembly - Farbe, Anstrich Colour, painting - Prüfung nach Verdrahtungsliste Test acc. to wiring list - Kabelabschirmung Cable screening - Erdungen Earthings - Schienenverbindungen Connections of busbars - Bezeichnungen Markings - Aussehen/Sauberkeit Visual appearance/cleanliness - Vollständigkeit Completeness	- Bestellzettel Order sheet - Zeichnung Drawing - Standprüfliste Checklist HUAD 603 031	3	LP	-	-	-	

INSPEKTIONS- UND PRUEFPLAN | [X] Standard | Liefereinheit
INSPECTION AND TESTPLAN | [ ] Order | Delivery Unit No.

TEIL: Umrichter-Block kpl.
ITEM: Converter unit compl.

Legende / Legend:
1 = Prüf-Nr. / test sequence No.
2 = Kundenref. Nr. / customer ref. No.
3 = Prüfungsdurchführung / test performed by
4 = Stand.-Bescheinigung / standard certificate
5 = Halte u.Meldepunkte / hold and witness points
6 = Nachweis f. Kunden / Records for customer
7 = Visum Inspektor / signature Inspector

1	2	Prüfpunkt/Merkmal Inspection point/ characteristic	Prüfung nach Inspection/test according to	3	4	5 H	 W	6	7
34		Bei der Prüfstelle In the test department - Sichtprüfung Visual check -Spannungs-und Isolationsprüfung Voltage and Insulation Test - Prüfung der Einstellungen und der Speisespannungen Check of Correct Settings / Supply Voltages - Funktionsprüfung Functional Test - Vollständigkeitsprüfung Visual Check for Completeness	- Bestellzettel Order sheet - Zeichnung Drawing - Prüfanweisung Test instruction HUAD 603 155	4	TR			TR	

INSPEKTIONS- UND PRUEFPLAN
INSPECTION AND TESTPLAN

[X] Standard
[ ] Order

Liefereinheit
Delivery Unit No.

TEIL
ITEM:

Umrichter - Anlage kpl.
Converter plant compl.

Legende
Legend:

1 = Prüf-Nr.
test sequence No.
2 = Kundenref. Nr.
customer ref. No.

3 = Prüfungsdurchführung
test performed by
4 = Stand.-Bescheinigung
standard certificate

5 = Halte u.Meldepunkte
hold and witness points
6 = Nachweis f. Kunden
Records for customer
7 = Visum Inspektor
signature Inspector

1	2	Prüfpunkt/Merkmal Inspection point/ characteristic	Prüfung nach Inspection/test according to	3	4	5 H	 W	6	7
45		Vor dem Versand Before shipping - Identifikation Identification - Vollständigkeit Completeness - Transportbedingungen Transportconditions * Packliste Packing list	Bestellung Order	5	*			-	

IP7_025270

INSPEKTIONS- UND PRUEFPLAN INSPECTION AND TESTPLAN	[X] Standard [ ] Order	Liefereinheit Delivery Unit No.

TEIL ITEM:	System kpl. System compl.

Legende Legend:	1 = Prüf-Nr. test sequence No. 2 = Kundenref. Nr. customer ref. No.	3 = Prüfungsdurchführung test performed by 4 = Stand.-Bescheinigung standard certificate	5 = Halte u.Meldepunkte hold and witness points 6 = Nachweis f. Kunden Records for customer 7 = Visum Inspektor signature Inspector

1	2	Prüfpunkt/Merkmal Inspection point/ characteristic	Prüfung nach Inspection/test according to	3	4	5 H	 W	6	7
66		Auf der Anlage On site	- Packliste Packing list	7	-	-	-	-	
		- Vollständigkeit Completeness	- Benutzerinformation User`s Manual						
		- Transportschäden Transport damages							
		- Inbetriebsetzung Commissioning		7	TR			TR	

ABB

Doc. no. 3BHS 119076
Rev. ind.
Date 15.01.01
From J.Hitz
Dept. IA-Q
Phone 056/299 25 24
Fax 056/299 45 14
E-mail josef.hitz@ch.abb.com

Factory Acceptance Test (FAT) Certificate for LCI-Converter

To: Customer / Representative

Copy: Project manager ABB

Customer: Customer-order no.:

Project: ABB-project no.:

Block no.: Date of test completion:

Place of testing:

Acceptance Test Responsibility

Execution: ABB, Dept.:

Release: Customer / Representative:

Test result

The converter has been tested according to the internal test specification 3BHS 118230 (Note: This is an internal document and for internal purposes only, presented at witness test, copying not allowed).
The exact test results are included in the test report 3BHS ________________
Confirmation of executed tests see page 2 and 3.

Findings were recorded No ☐ Yes ☐

If findings were recorded see "list of findings" on page 4.

Follow up inspection Not needed ☐ Needed ☐

Remark:
This document can also be given to the customer before the execution of the tests. In this case the customer can choose which tests he would like to witness during the factory acceptance test.

Certification
This certifies that the acceptance test has been satisfactorily completed and the material can be released for delivery to the customer

Date	Signature Test Lab. Engineer	Signature Manager Test Lab.	Signature Customer/Representative

Confirmation of executed tests

	Executed before FAT	Executed during FAT	Customers ITP-no.: ITP-items
1. Checks before electrical testing	[x]	[ ]	[ ]
2. Voltage / Insulation test	[x]	[ ] 1)	[ ]
3. Check of low voltage distribution	[x]	[ ]	[ ]
4. Preparation of the electronic	[x]	[ ]	[ ]
5. Leakage and pressure test (only if converter water cooled)	[ ]	[ ]	[ ]

1. **Checks before electrical testing**
   - Main data
   - Optical and mechanical check
   - Completeness and correctness
   - Internal wiring and connections
   - External wiring and connections
   - PCB supplementary outfit / Setting values
2. **Voltage / Insulation test**
   - Check of circuitry and data
   - Check of air and creeping distances
   - Voltage and insulation test
   - Voltage test of converter components
3. **Check of low voltage distribution**
   - Low voltage supply
   - Low voltage distribution
4. **Preparation of the electronic**
   - Rack compound
   - Serial interface
   - Configuration of control panel
   - Configuration of arcnet devices
   - Download of FUPLA Software
   -
5. **Leakage and pressure test** (only if converter water cooled)
   Leakage and pressure test is performed on the secondary circuit (deionized water circuit) of the cooling unit together with the converter.

1) Test not possible during FAT

6. Check of the converter components The function of the converter components are tested step by step	X		
7. Functional test without high voltage - Testprogram 1: Firing pulses line side SRN - Testprogram 2: Firing pulses machine side SRM - Testprogram 3: Pulse logic - Testprogram 4: Excitation	X		
8. Functional test with high voltage - High voltage supply and reference voltage - Testprogram 5/6: Short circuit operatio	X		
Additional Test (Option) **9. Functional test with high current (rated current)** - Low voltage supply and reference voltage, high current. - Testprogram 5/6: Short circuit operation	X		

Remarks:

Doc. no. 3BHS 119076
Rev. ind.
Date 15.01.01

List of findings

No.	Finding Description	Respon sible	Cleared date Planned	Cleared date Real	Cleared sign.

REVISION

Rev.	Page (P) Chapt. (C)	Description	Date Dept./Init.
-			

Standard Document Submittal List (DSL)

MEGADRIVE LCI

Remarks:

One DSL per order
Documents marked with (X) are not standard documents for the specific product

No.	Title	Document number	Issue code for documents	Only applicable for LCI			Delivery Time			Remarks
			S = Standard P = Project specific I = For inform. A = For approval	DR	SO	ST	A) after Order B) after kick-off C) after techn. clarified X) delivery date		Actual delivery date	
							Standard	Option		
1	**General documentation**									
1.1	Fundamental data sheet template (Standardized questionnaire)		S	X	X	X	With the order, Data filled in by client			Necessary input data for converter design, must be available for kick-off
1.2	Functions description		S	X	X	X	With the order, Data filled in by client			Necessary input data for converter design, must be available for kick-off
1.3	3-Line Block Diagram including interface details	3BHS xxx	P	X	X	X	4 weeks after B)			
2	**Design data**									
2.1	Design Data (including start-up characteristic, voltage and current diagrams)	3BHS xxx	P	X	X	X	4 weeks after B)			With detailed data for design
2.2	Harmonic Distortion	3BHS xxx	P	(X)	(X)	(X)	4 weeks after B)	X		Considering a pure inductive network
2.3	Pulsating Torques	3BHS xxx	P	(X)				X		

3	**Mechanical Arrangement**									
3.1	Layout drawing (incl. Protection class and weight)	3BHS xxx	P	X	X	X	4 weeks after B)			
3.2	Connection Plan (location of HV bus bars terminals, water flanges)	3BHS xxx	P	X	X	X	12 weeks after B)			
4	**Detail drawings & documents**									
4.1	Consumer List	3BHS xxx	P	(X)	(X)	(X)		X		
4.2	Converter Hardware Diagram incl. Electrical parts list	3BHS xxx	P	X	X	X	12 weeks after B)			Preliminary, final version with User manual
4.3	Converter Sequence Diagram	3BHS xxx	P	(X)	(X)			X		Optional document
4.4	List of Signals Serial Interface	3BHS xxx	P	(X)	(X)	(X)		X		Only if serial interface is included in scope
4.5	Supplementary Outfit PCB's	3BHS xxx	P	X	X	X	4 weeks after X)			Appendix of User manual
4.6	FUPLA Software	3BHS xxx	P	X	X	X	4 weeks after X)			Appendix of User manual
4.7	Cooling Unit Flow Diagram	3BHS xxx	P	X	X		4 weeks after B)			Water Cooled drives only
4.8	Cooling Unit Data Sheet	3BHS xxx	P	X	X		12 weeks after B)			Water Cooled drives only
5	**Test & Inspection**									
5.1	Manufacturing and testing schedule	3BHS xxx	P	X	X	X	2 weeks after B)			
5.2	Standard inspection and test plan (I&TP) LCI Air Cooled	3BHS101197	S	X	X	X	2 weeks after B)			Air cooled drives only
5.3	Standard inspection and test plan (I&TP) LCI Water Cooled	3BHS101198	S	X	X	X	2 weeks after B)			Water cooled drives only
5.4	Test protocols (certificates)	Order-no. / Converter	P	X	X	X	1 week after X)			Appendix of *User manual*

		serial no.								
6	**Manuals**									
6.1	Users manual chapter 1: Transportation and storage	3BHS xxx	P	X	X	X	8 weeks before X)			Part of user manual
6.2	Users manual Complete	3BHS xxx	P	X	X	X	4 week after X)			Incl. Component location drawings, 2 pcs. CD ROM, 3 pcs. Hard-copies only on request
6.3	As built documentation		P	X	X	X				After commissioning

REVISION

Rev. ind.	Page (P) Chapt.(C)	Description	Date Dept./Init.
-		First issue	14.08.03/ ATDE

Product Course

LCI Operation - Maintenance - Troubleshooting LCI

Description

The ABB MEGADRIVE LCI is a variable frequency drive system using large synchronous machines, thyristor converters and a isolation transformer.
The LCI is suitable for drive applications like pumps, fans, test-stands, etc. with a power range of up to 100 MW and output frequencies between 0 and 120 Hz.

Objectives

The participants will learn how to operate, maintain and troubleshoot the LCI drive system.

Upon completion of this course, the participants will be able to understand the drive system topology, to locate and replace faulty hardware components and to carry out preventive maintenance.

Using available programming and troubleshooting tools will be trained by practical exercises.

Contents

- General Topics
  Introduction to Product
  Different DC bus configurations
  Medium voltage safety requirements

- Hardware Description (Power Electronics & Control)
  Functions of components and PCB's (printed circuit boards)
  Hardware schematics and electrical drawings
  PCB settings and configurations

- Watercooling System
  Cooling circuit description
  Preventive maintenance

- Operation
  Energizing and de-energizing the converter
  Start / stop sequence
  Using local control panel

- Software Introduction
  rectifier, inverter and excitation software concept
  Data exchange between modules
  Setting parameters

- Fault-tracing and Troubleshooting
  Interpretation of alarm and fault messages
  Replacement of PCB's and components
  Getting help from ABB

Methods

Lectures and demonstrations
Practical exercises at unit

Participants

Electricians, technicians and engineers who will operate, maintain or troubleshoot the LCI drive system.

Prerequisites

Basic knowledge on synchronous motors and drive engineering
English speaking (all documents in English)

Duration

4 days

Add

Max. 6 participants

Nr.	Customer Country	Plant Load Machine Branch	Qty.	Shaft Power [MW]	Speed [rpm]	Speed Range [%]	Motor Voltage [kV]	Frequency [Hz]	Year of Delivery	Remarks
1	Engineering Managing Services (EMS) RSA	 Chemistry Compressor	1	4.7	1640	60 ... 100	1.8	53	1980	
2	Messerschmitt- Bölkow-Blohm GmbH Germany	Bremerhaven Windturbine Research	1	0.45	1350	10 ... 100	1.1	45	1981	
3	Nova Calgary Canada	 Compressor Gas	1	6.2	2100	57 ... 100	1.1	70	1982	
4	Sasol RSA	 Compressor Chemistry	1	4.8	1500	70 ... 100	1.2	50	1983	1. Digit. Control
5	Brown Boveri Switzerland	Birr Teststand Research	2	10	6000	14 ... 100	5.7	100	1983	High speed drive
6	SAMIM Sardinia Italy	Porto Vesme Fan Chemistry	1	2.1	1500	34 ... 100	1.3	50	1984	
7	Shell Norway Norway	Sola Compressor Oil Refinery	1	2.0	1800	66 ... 100	2x1.1	60	1985	
8	ESCOM / MAN RSA	Matimba B.F. Pump Power Plant	19	9.6	6000	33 ... 100	2x2.9	100	1985/90	High speed drive
9	Shell USA USA	Wood River Compressor Chemistry	2	5.3	1800	50 ... 100	2x1.1	60	1985	

Nr.	Customer Country	Plant Load Machine Branch	Qty.	Shaft Power [MW]	Speed [rpm]	Speed Range [%]	Motor Voltage [kV]	Frequency [Hz]	Year of Delivery	Remarks
10	Shell USA USA	Wood River Blower Chemistry	4	2.7	5900	67 ... 100	2x1.1	98	1985	High speed drive
11	Hammarbyverket Stockholm Sweden	 Pump Distr. Heat.	4	1.0	1070	30 ... 100	0.66	53	1985	
12	Stolt Nielsen USA	 Shaft Gen. Marine	7	0.95	115	50 ... 100	0.66		1985	
13	ESCOM / MAN RSA	Kendal B.F.Pump Power Plant	19	8.0	5521	33 ... 100	2x2.9	92	1986/91	High speed drive
14	EniChem Italy	Porto Torres Compressor Chemistry	1	13	6400	80 ... 100	2x3.7	106	1986	High speed drive
15	Kanton Zurich Amt f. tech. Anlagen Switzerland	Aubrugg Pump Distr. Heat.	1	0.9	1500	33 ... 100	1.38	50	1986	
16	Shell Hycon The Netherlands	Pernis Compressor Petro Chem.	1	5.25	6000	50 ... 100	2x2.6	100	1986	High speed drive
17	Shell Hycon The Netherlands	Pernis Pump Petro Chem.	1	2.4	6000	50 ... 100	2x1.3	100	1987	High speed drive
18	NAM BV Assen The Netherlands	Kootstertille Recipr.Compr. Gas	2	3.9	365	50 ... 100	2x2.1	49	1987	

Nr.	Customer Country	Plant Load Machine Branch	Qty.	Shaft Power [MW]	Speed [rpm]	Speed Range [%]	Motor Voltage [kV]	Frequency [Hz]	Year of Delivery	Remarks
19	KKW Mühleberg Switzerland	Mühleberg B.F. Pump Power Plant	2	3 4	3000	76 .. 100	2x1.05	50	1987/88	Nuclear Power Pl.
20	Belgo Mineira Brazil	 Wire Block Metallurgy	1	6 8	1700	50 ... 100	2x2.4	57	1988	
21	Statoil Norway	Veslefrikk 1 Compressor Oil-offshore	1	7.45	1800	80 ... 105	2x2.4	63	1988	
22	Statoil Norway	Veslefrikk 1 Compressor Oil-offshore	1	4.5	1800	80 ... 105	2x1.45	63	1988	
23	Steag Germany	Herne 4 B.F. Pump Power Plant	2	13	5700	10 ... 100	2x2.7	95	1988	High speed drive
24	NAM BV Assen The Netherlands	Annerveen Recipr.Compr. Gas	3	4.725	375	50 ... 100	2x2 5	50	1988	
25	SWCC Riyadh Saudi Arabia	Qassim Pump Water	10	3.3	1800	10 ... 110	2.3	66	1988	
26	SWCC Riyadh Saudi Arabia	Qassim Pump Water	8	1.5	1200	10 ... 110	1.3	66	1988	
27	CNTIC P.R. of China	Pan Jia Kou Pump Power Plant	1	60	148	60 ... 100	13,8	50	1988	Largest LCI 1988

Nr.	Customer Country	Plant Load Machine Branch	Qty.	Shaft Power [MW]	Speed [rpm]	Speed Range [%]	Motor Voltage [kV]	Frequency [Hz]	Year of Delivery	Remarks
28	Pirelli *Italy*	Rubber Mixer *Rubber*	1	2.7	1200	25 ... 100	2x1.1	60	1989	
29	PE Isando	Blower Research	1	22	1400	30 ... 100	2x3,7	4,67	1988	
30	Stockholm Energy Sweden	Värtan Pump Distr.Heat.	3	2.1	1150	78 ... 100	1.1	57	1989	
31	Fagersta Steel Sweden	Wire Block Metallurgy	1	2.8	1100	50 ... 100	2x1.37	55	1989	
32	Electricidade de Portugal Portugal	PEGO B.F.Pump Power Plant	1	8.26	4800	81 ... 109	2 x 2.79	88	1990	High speed drive
33	Von Roll AG Switzerland	Gerlafingen Wire Block Metallurgy	1	5.0	1500	60 ... 100	2 x 2.55	50	1991	
34	EPZ Eindhoven The Netherlands	Amer 9 Pump Power Plant	2	4.9	1500	40 ... 100	2 x 1.25	50	1991	
35	Kanton Zürich Amt f. techn. Anlagen Switzerland	HKW Aubrugg Pump Distr. Heat.	1	0,90	1500	33 ... 100	1.38	50	1990	
36	Boston Edison USA	Mystic Station I.D. Fan Power Plant	2	5.48	890	45 ... 100	2 x 2.0	60	1991	2 x 6-pulse circuit

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Nr.	Customer Country	Plant Load Machine Branch	Qty.	Shaft Power [MW]	Speed [rpm]	Speed Range [%]	Motor Voltage [kV]	Frequency [Hz]	Year of Delivery	Remarks
37	Hylsa Mexico	Pueblo Wire Block Metallurgy	1	4.8	1450	60 .. 100	2 x 1,45	60	1991	
38	Krupp Germany	Hagen Wire Block Metallurgy	1	3.2	1300	46 ... 100	2 x 1,55	65	1991	
39	Neste Polimeros S.A. Portugal	Sines Extruder Chemistry	1	5,8	1500	10 ... 100	2 x 2,0	50	1991	
40	Electricidade de Portugal Portugal	PEGO B.F.Pump Power Plant	1	6.68	4655	83 . . 113	2 x 2.79	87	1993	High speed drive
41	Shell The Netherlands	Pernis Compressor Petro Chem	1	6.3	1575	70 ... 105	2 x 2 8	52.5	1992	Converter installed in air conditioned container
42	BMW Rolls Royce Germany	Munich Compressor Test bed	1	18	5500	12 ... 100	2 x 3.5	91.67	1992	High speed drive Converter installed in air conditioned container
43	LUCKY HOECHST South Korea	YEO CHUN Extruder Chemistry	1	5.5	1185	10 ... 100	2 x 2,0	60	1991	
44	NASA USA	Moffet Field Fan/Blower Research	1	11 5	500	10 ... 100	2 x 2.75	50	1992	
45	Chevron Chemicals USA	Pascagoula Compressor Petro Chemical	1	11.2	5800	55 ... 100	2 x 3,0	96	1992	Largest High Speed in USA

Nr.	Customer Country	Plant Load Machine Branch	Qty.	Shaft Power [MW]	Speed [rpm]	Speed Range [%]	Motor Voltage [kV]	Frequency [Hz]	Year of Delivery	Remarks
46	DSM The Netherlands	Extruder Chemistry	1	4.0	1550	22 ... 100	2 x 1.25	51.7	1992	
47	Malaywata Steel Berhard Malaysia	Wire Rod block Metallurgy	1	3.7	1585	57 ... 100	2 x 1.1	52.8	1992	
48	Nueva Montana Quijano Spain	Wire Rod Block	2	3.2	1100	55 ... 100	2 x 1.2	55	1992	
49	Statoil Norway	Kårstö Compressor Oil & Gas	3	7.5	1890	66 .. 100	2 x 1.5	63	1992	
50	PSI Energy USA	Gibson 4 ID Fan Power Plant	4	5.45	900	47 ... 100	2 x 3	60	1994	2 drives in 1 cotainer installed each drive 2x 6pulse circuit
51	Norske Shell Norway	Troll Phase 1 Compressor Gas	5	41.5	3750	66 ... 105	2 x 6,5	63	1993	
52	RAG, Essen Germany	Prosper Compressor Mining	1	5.0	1500	20 ... 100	2 x 1.8	50	1993	
53	Tianjin Steel Works P.R of China	Tianjin Rod Block Metallurgy	1	6.0	1700	50 ... 100	2 x 1.45	50	1993	
54	VEBA Kraftwerke Ruhr AG Germany	KW Schkopau B.F. Pump Power Plant	4	12.5	5150	10 ... 100	2 x 3.5	85.8	1994/1995	

Nr.	Customer Country	Plant Load Machine Branch	Qty.	Shaft Power [MW]	Speed [rpm]	Speed Range [%]	Motor Voltage [kV]	Frequency [Hz]	Year of Delivery	Remarks
55	Xiantan P.R. of China	Rod Block Metallurgy	1	6.3	1570	54...100	2 x 1.5	52.3	1993	
56	CF & I Rod & Bar Mill USA	Rod Block Metallurgy	1	6.8	1570	54...100	1 x 1.5	52.3	1994	
57	Statoil Norway	Sleipner Vest Compressor Oil & Gas	2	10.8	1800	70...105	2 x 2850	63	1994	
58	Shell The Netherlands	Pernis Compressor Petro Chem.	1	6.4	1720	70...105	2 x 2550	57	1995	
59	ESCO Iran	Rod Block Metallurgy	1	5.0	1500	60...100		50	1994	
60	Norsk Jernverk Norway	Rod Block Metallurgy	1	5.7	1500	60...100		50	1994	
61	Anshan Steel Works P.R. of China	Rod Block Metallurgy	3	4.0	1800	60...100		60	1994	
62	Bautou Steel Works P.R. of China	Rod Block Metallurgy	1	6.0	1570	54...100		52	1994	
63	Southern Steel Berhad Malaysia	Penang Rod Block Metallurgy	1	5.7	1500	60...100		50	1994	

Nr.	Customer Country	Plant Load Machine Branch	Qty.	Shaft Power [MW]	Speed [rpm]	Speed Range [%]	Motor Voltage [kV]	Frequency [Hz]	Year of Delivery	Remarks
64	Statoil Norway	Veslefrikk 1 Compressor Oil & Gas	1	5.2	1800	70...105	2 x 1450	63	1995	Offshore
65	NLR The Netherlands	HST-Drive Fan Test stand	1	19	620	76...100	2 x 3.4	52	1996	Wind-tunnel
66	Reliance Industries India	Hazira Extruder Chemical	1	2.4	1000	50...100	2 x 0.9	50	1995	
67	NASA-Langley USA	Research Center Blower Test stand	1	101	600	10...100	2 x 12.5	60	1997	Wind-tunnel
68	Sipasa Brazil	Finishing Block Metals	1	4.5	1500	60...100	2 x 1.2	50	1995	
69	North Star Steel USA	Finishing Block Metals	1	7.2	1800	66...100	2 x 1.2	60	1995	
70	Cascade Steel USA	Finishing Block Metals	1	5.0	1500	60...100	2 x 1.2	50	1995	
71	KIA Steel Korea	Finishing Block Metals	1	6.0	1500	57...100	2 x 1.2	50	1995	
72	Krakatau Steel Indonesia	Finishing Block Metals	1	5.0	1400	50...100	2 x 1.2	46.7	1995	

Nr.	Customer Country	Plant Load Machine Branch	Qty.	Shaft Power [MW]	Speed [rpm]	Speed Range [%]	Motor Voltage [kV]	Frequency [Hz]	Year of Delivery	Remarks
73	American Steel & Wire USA	Finishing Block Metals	1	6.8	1650	52...100	2 x 1.2	55	1995	
74	Chia I Taiwan	Finishing Block Metals	2	3.65	1200	56...100	2 x 1.0	60	1995	
75	Pacific Steel New Zealand	Finishing Block Metals	1	5.4	1350	60...100	2 x 1.2	45	1996	
76	Yu-Din Taiwan	Finishing Block Metals	1	5.0	1500	63...100	2 x 1.2	50	1996	
77	ANSDK EL DIKHEILA Egypt	Finishing Block Metals	1	4.5	1500	60...100	2 x 1.2	50	1996	
78	Thai Special Steel Ind. Thailand	Finishing Block Metals	1 1	5.0 3.2	1600 1700	53...100 50...100	2 x 1.0 2 x 1.0	53.3 56.7	1996 1996	
79	LG Petrochemical Korea	Extruder Chemicals	1	5.5	1185	50 ...100	2 x 2.0	60	1996	
80	Aeronautical Maritime Res Laboratory Australia	Blower Research	1	5.3	1800	10 .. 100	2 x 1 56	60	1996	
81	Nigeria LNG Ltd.Bonny Island Nigeria	Compressor Gas	4	8.7	3600		2 x 2.915	60	1997	

Nr.	Customer Country	Plant Load Machine Branch	Qty.	Shaft Power [MW]	Speed [rpm]	Speed Range [%]	Motor Voltage [kV]	Frequency [Hz]	Year of Delivery	Remarks
82	Trinecke Zelezarny Czech Republic	 Wire & Rod Mill Metals	2	6.3	1700	53 ... 100	2 x 1.2	56.7	1996	
83	Krakatou Steel Indonesia	 Finishing Block Metals	1	5.0	1400	50 ... 100	2 x 1.2	46 7	1996	
84	Aero Gasdynamic & Vibration Laboratory Indonesia	Tangerang Blower Research	1	30.5	800	10 ... 105			1998	
85	Ansdk El Dikheila Egypt	 Wire Rod Mill Metals	1	4.5	1500	60 ... 100	2 x 1.2		1996	
86	Arco Steel Egypt	 Wire Rod Mill Metals	1	4.0	1500	60 ... 100	2 x 1.2		1997	
87	Baoshan P. R. of China	 Wire Rod Mill Metals	1	4.8	1550	55 ... 100	2 x 1.2		1998	
88	Baoshan P R. of China	 Wire Rod Mill Metals	1	3.2	1700	50 ... 100	2 x 1.0		1998	
89	Tycoon Steel Thailand	 Wire Rod Mill Metals	1	5.0	1500	63 ... 100	2 x 1.2		1998	
90	Wingas Germany	Weissweiler/Rehden Compressor Gas	3	12.5	1800	70 ... 105	2 x 3.3	60	1998	

Nr.	Customer Country	Plant Load Machine Branch	Qty.	Shaft Power [MW]	Speed [rpm]	Speed Range [%]	Motor Voltage [kV]	Frequency [Hz]	Year of Delivery	Remarks
91	Hyundai South Korea	 Test stand Research	1	5.0	720	10 ... 100	2 x 1.1	48	1997	
92	Agency for Defence Development South Korea	 Blower Research	1	2.4	600	10 ... 103	2 x 1.1	50	1997	
93	Danieli Mexico	 Wire Rod Mill Metals	1	5.4	1500	25 ... 100	2 x 1.1	50	1997	
94	National Gas Pipeline Company of America, USA	Station 305 Compressor Gas	1	16.4	1800	60 ... 105	2 x 3.4	60	1999	
95	Statoil Norway	Veslefrikk/Huldra Compressor Oil and Gas	1	10.6	1800	80 ... 105	2 x 1.6	60	1999	
96	SAGA Norway	Snorre B Compressor Gas	1	9.6	1800	70 ... 105	2 x 1.4	60	1999	
97	SK Energi Denmark	Awedorewaerhet Feed Boiler Pump Power Plant	1	15	1800	35 ... 100	2 x 3.4	60	2000	
98	Nigeria-LNG Ltd. Expansion Project, Nigeria	Bonny Island Compressor Gas	2	10	3600	90 ... 100	2 x 3.16	60	2000	
99	Hitachi Ltd. Omika Works, Japan	Mubarak Pump. Station, Egypt	21	12	300	70 ... 100	2 x 2.95	50	2000/01	

Nr.	Customer Country	Plant Load Machine Branch	Qty.	Shaft Power [MW]	Speed [rpm]	Speed Range [%]	Motor Voltage [kV]	Frequency [Hz]	Year of Delivery	Remarks
100	Exxon/Mobil Great Britain	Mobil Skene Compressor Gas	1	14	1800	70 … 100	2 x 3.9	60	2000	Off Shore Application
101	P&O Cruise Liners Aker Shipyard Germany	AIDA II, III Propulsion	4	9.4	152	0 … 106	2 x 1.9	60	2001/2002	
102	Ras Gas Ltd Qatar	Ras Laffan Train 3 Compressor Gas / LNG	2	12	3600	95 ... 101	2 x 3.2	60	2002	LNG Plant
103	Woodside Ltd Australia	Woodside Compressor Gas / LNG	1	11	3600	95 ... 101	2 x 3.3	60	2002	LNG Plant
104	Woodside Ltd Australia	Woodside Compressor Gas / LNG	1	20	3600	95 .. 101	2 x 3.8	60	2002	LNG Plant
105	Petrobras Brasil	Barracuda Compressor Gas	3	14.2	1800	70 … 105	2 x 3 6	60	2001	FPSO Unit P43 Off Shore
106	Petrobras Brasil	Caratinga Compressor Gas	3	14.2	1800	70 … 105	2 x 3.6	60	2001	FPSO Unit P 48 Off Shore
107	Woodside Ltd Australia	Woodside Compressor Gas / LNG	1	16.5	4225	95 … 101	2 x 3.8	60	2002	LNG Plant
108	Petrobras Brasil	Caratinga Compressor Gas	3	14.2	1800	70 … 105	2 x 3.6	60	2002	FPSO Unit P 50 Off Shore

Nr.	Customer Country	Plant Load Machine Branch	Qty.	Shaft Power [MW]	Speed [rpm]	Speed Range [%]	Motor Voltage [kV]	Frequency [Hz]	Year of Delivery	Remarks
109	AEDC Tullahoma USA	Arnold AFB Compressor Test-stand	2	30	3600	0 ... 100	13.2	60	2002 2003	Wind-tunnel system Soft-Starter
110	AEDC Tullahoma USA	Arnold AFB Compressor Test-stand	2	50	600	10 ... 100	2 x 6.5	60	2003	Wind-tunnel system
111	Ras Gas Ltd Qatar	Ras Laffan Train 4 Compressor Gas / LNG	2	12	3600	95 ... 101	2 x 3.2	60	2003	LNG Plant

Total - Projects	:	111
Total - Drive units	:	243
Total - Power rating	:	2265 MW
Status	:	April 26, 2002

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References - Contacts

Five projects with contact information. See Block number as cross reference.

Block Nr. 516/517
ASTF (Retrofit of ABB converter)
Client: AEDC, Tullahoma
Contact: Bill Myers
Tel. 931-454-6083

Block Nr. 178
Rocky Mountain Hydroelectric Plant
Client: Oglethorpe Power, Rome (Georgia)
Contact: Julio A. Trujillo
Tel. 706-290 5428

Block Nr. 270
Racoon Power Plant (Retrofit of non ABB converter)
Client: TVA (Tennessee Valley Authority)
Contact: Ron Pettit
Tel. 423-825 3077

Block Nr. 295
Cartes Dam
Client: US Army Corps of Engineers
Contact: Rick Brannan
Tel. 706-334 2906

Block Nr. 77/78
Mühleberg Switzerland, Nuclear power Plant
Client: BKW (Bernisch Kraftwerke)
Contact: Mr. Gehri
Tel. +41 31 754 7637

RELIABILITY, AVAILABILITY AND MAINTAINABILITY (RAM) OF HIGH POWER VARIABLE SPEED DRIVE SYSTEMS (VSDS)

Paper No PCIC - 98-16

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I. ABSTRACT

This is an overview of various aspects of Reliability, Availability and Maintainability of Large AC Drives (medium voltage and >5 MW). The focus is on the definition and practical use of the relevant and most frequently used terms in this field, with the purpose to provide a base for common understanding between customers and suppliers. It is also mentioned how reliability evaluation procedures have been applied in a few cases. Reference is made to typical misinterpretations. The overview is limited to electric drives and does not include comparisons with other drive systems like gas- and steam turbines.

II. INTRODUCTION

Reliability is the most important feature of a drive. It is repeatedly found, that users of VSDSs are placing reliability on top of the wish list. What can be seen, however, is that the word reliability is so "loaded" with different expectations and individual interpretations, that it can be difficult to immediately convert the requirement into more technical information that can be used by, for example, a development department.

If customers are asking for reliability, that is what they should get. But it has to be the kind of reliability that they are actually looking for. It is therefore important to clarify the reliability terminology, so that users and manufacturers talk the same language and will understand one another when this subject is being discussed.

The subject of calculated reliability, normally expressed with the Mean Time Between Failures (MTBF), needs to be better understood by both the supplier and the user. The span of parameters given in the IEEE Gold Book [1] can be used to calculate two figures of MTBF, both of which are "correct" but still very far apart. The following is an attempt to clarify how MTBF calculations should be used.

III. PREREQUISITES

A. Drives overview

It is indicated in figure 1 what is meant by an electric Variable Speed Drive System (VSDS) and a Static Frequency Converter (SFC). Where actual figures are given in this paper, they are referring to the Load Commutated Inverter (LCI) synchronous motor drive system. It should be stated however, that the general information is valid for all systems.

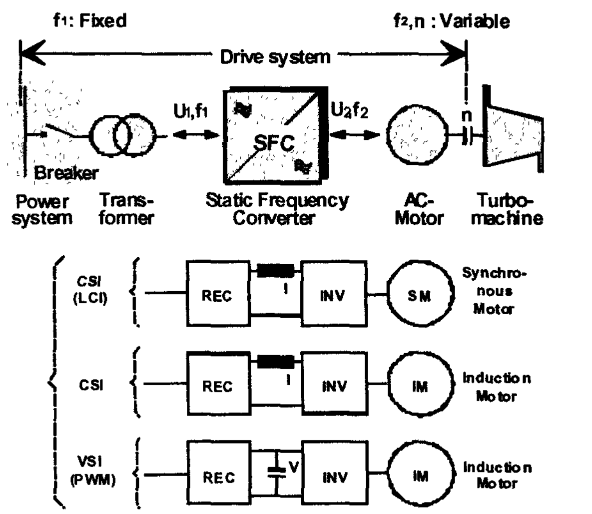

Fig. 1. The relevant Large AC Drive Systems

B. Prerequisites for reliability

It must be pointed out, that problems related to products that are not yet fully developed and run in, or systems for which the application engineering is insufficient, are not included in the reliability appraisal. However, such problems do exist. They are found in areas like:

- Requirement specifications that are not in line with the actual situation (not reflecting the operating or environmental conditions).
- Drive concepts and hardware designs with basic mistakes.
- Drive software that is still lacking the necessary robustness.

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- Inadequate care taken in the application of the drive into its operational environment, especially the mechanical interfacing to the driven load (vibrations) and the electrical interface to the power supply (harmonics).

In order to avoid problems relating to the above areas, the customer and supplier need to have a solid partnership and cooperation from the beginning of the project. It is further recommended that the customer procures the complete drive system, including system engineering and commissioning, from one competent supplier.

Only when all such issues are cleared is it possible to start to communicate on reliability and availability matters.

It also needs to be pointed out, that the reliability of the electric supply will not be dealt with in this paper although this of course is an important issue. Short interruptions (up to a couple of seconds) are normally not a problem for the drive but they can become a problem for the application.

IV. RAM, DEFINITIONS AND TERMS

The abbreviation RAM (Reliability, Availability, Maintainability) encompasses the essential features of reliability in general. These features are interrelated in such a way that it is necessary to have both a high reliability and a good maintainability in order to achieve a high availability.

A VSDS manufacturer that is planning and designing a system for which reliability specifications must be met, is faced with the problem of how to estimate the system reliability and how to compare alternative designs. He needs criteria and corresponding figures to be able to rate different lay-outs and designs.

In spoken English the term reliability is used to express the capability of a unit or a system to stay functional. In the theory of reliability, this capability is expressed by the probability R(t), that the required function will be provided during a certain duration (T) under the given operational conditions.

A. *RAM- Analysis*

In order to be able to make the RAM-analysis, it is important to know the terminology and to understand the method of analysis and calculation. The definitions of the terms are based on statistics and are valid only when a sufficient number of similar equipment has been in operation over a sufficient length of time. Both the calculated figures for the VSDS and those obtained from field experience meet these criteria. However, it can already be said at this point, that the figures derived from field experience are far better than the calculated ones.

B. *Terms and definitions*

The terms that have the most practical importance and that are generally accepted and most commonly used in reliability considerations are: **Mean Time Between Failures** (MTBF), **Mean Time To Repair** (MTTR) and **Availability** (A). In order to provide a better understanding, a few additional terms are also defined.

(1) The Failure Rate (λ) of an item (component, assembly, system etc.) is a figure for the mean number of failures per unit time. The rate is thus considered as time-independent during the useful life period (no more infant mortality and not yet any age-related failure rate increase). The failure rate figures are expressed in FIT (Failures In Time) with one FIT being equal to 10^{-9} failures per hour. To get a feeling for this FIT number, it has to be kept in mind that a component with a failure rate of about 100 FIT is statistically failing only once per 1000 years. In the reliability analysis, the failure rate has a fundamental meaning. Assembly failure rates are calculated bottom up from component figures.

(2) The Mean Time Between Failures (MTBF) of any item with constant failure rate and no redundancy is the inverse of its failure rate, normally expressed in hours (or years): MTBF = $1/\lambda$. For more complex structures with redundancy, the MTBF is calculated mathematically from: MTBF $= \int_0^\infty R(t)\,dt$ where R(t) is the reliability function. MTBF is the basic criterion for the practical evaluation of VSDS drive reliability. A very common mistake is to interpret the MTBF to represent the time before which there is no failure. The MTBF calculation can be based on assumed failure rates of the components that make up the system, or on the basis of observed failures in a large enough population of installed drives that have been in operation long enough for statistic methods to be valid.

(3) The Mean Time To Repair (MTTR) is the average time it takes to eliminate a failure and put the drive back in operation (time for all activities from trip to restart). This time is heavily dependent on good maintainability such as a suitable diagnostic system, spare parts at hand and skill level of troubleshooting personnel (Ref. to 0. XI. REDUNDANCIES").

(4) The Availability (A) of a system or an assembly is the probability to find it in proper service condition at any point of time. Availability is expressed as:

A = (MTBF)/(MTBF+MTTR).

The requirements to obtain a high availability are a high MTBF and a low MTTR. Contrary to the practice in mechanical drive systems, the time for scheduled maintenance is not part of the availability definition.

(5) The Mission Profile of a drive is the specification of the function it has to fulfill dependent on time. For example are stops planned in the cycle or is it a continuous operation?

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The reliability statements have to be related to the mission profile.

(6) The Reliability function R(t) expresses the probability that the system will operate without failure over the time interval 0→t. It plays a role in the analytical derivation of the other reliability terms and in checking the accuracy of their approximations. Its value in the practical evaluation is of less importance.

V. COMMON MISUNDERSTANDINGS

It is a fact that engineers of different disciplines often use different definitions for reliability terms. Here are a few examples:

- Reliability is often confused with Availability. One often hears the question: "How reliable is the drive ?", and later on one finds out that what the person really meant was: "What *availability can be assumed ?" In gas turbine circles* for instance, it is customary to define the reliability as:
  R = (Total time - unscheduled maintenance)/(Total time)
  which is quite different from the practice in electric drive circles. The availability definition, however, has similarities to the definition used in this paper.
  A=(Total time -(planned+unscheduled) maintenance)/(Total time)
  When gas turbines are referred to in advertisements, and figures for their reliability are mentioned, expressions like : "demonstrated reliability" or "demonstrated availability" are used. With this is meant that one specific unit has displayed the reported performance.

- "Homemade" expressions to calculate the MTBF of a *power bridge with legs that have one redundant thyristor* can lead to the wrong result, although such expressions may appeal to common logic thinking. The most common mistake is to assume that in a converter with, for example, 24 legs, the second thyristor that will fail does so in the leg where the first thyristor failed because of the increased stress on the remaining thyristors. The more thyristors per leg, the less is the impact of the increased stress. However, one also has to take into account the probability that any other set of two thyristors can fail in any other leg and the importance of this fact increases with the number of legs. Using the 24 leg converter with 3 out of 4 thyristor redundancy as example, the result would be an MTBF of 190 years instead of the correct 94 years.

- Expanding the use of an equivalent λ in a structure with redundancy can lead to errors. This is best clarified in an example. Take a thyristor bridge with 24 legs, each with a redundant thyristor.

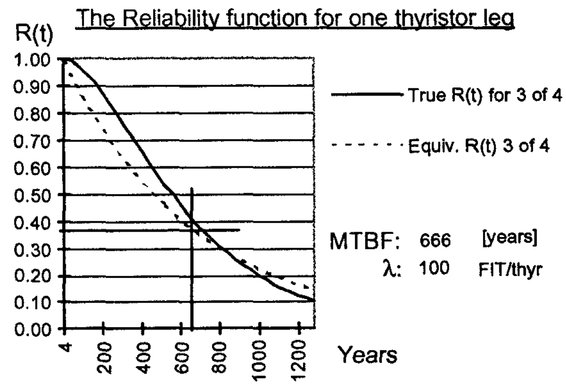

Fig. 2. The Reliability function for thyristors in a leg.

The reliability for one leg of thyristors can be approximated *with an exponential function (Ref. to Fig. 2) that would give* the same MTBF as the one obtained by the true R(t) reliability function. However, when calculating the overall MTBF for 24 legs, the error will be quite large if this equivalent λ is used in the expression $\lambda_{tot} = 24{*}\lambda$. (In the example above, an MTBF of 27.7 years instead of the correct 94 would be the result). Here it is essential to go back to the definition and calculate $R^{24}(t)$ as the resultant reliability function, and integrate it to get the MTBF figure as explained in the definitions above.

VI. METHOD OF ANALYSIS

The overall reliability of the drive system is determined by a 'bottom up' calculation applied to the drive's reliability structure (Fig. 3).

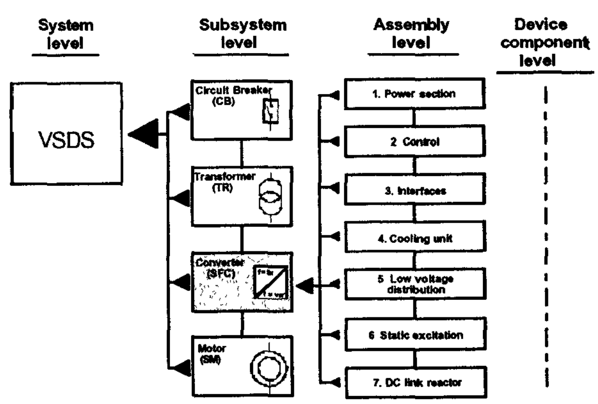

Fig. 3. Drive reliability block diagram

First the drive's functional structure is analyzed in a 'top down' approach, based on system block- and circuit diagrams, lists of components, description of interfaces, etc. The whole drive system is thus reduced step-by-step to

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convenient functional modules, i.e. it is broken down to subsystem-, assembly- and component levels. Secondly FMEA (Failure Mode and Effect Analysis) is applied to all levels of the functional structure. The influence of component failures on assembly, subsystem and finally on the entire system is hereby documented. Modeling the drive's reliability structure (Ref. to Fig. 3) is done 'bottom up'. This means that first the smaller units are evaluated and then on the basis of these, the larger ones, until the entire system is evaluated.

The VSDS is actually divided into 4 subsystems. From a reliability point of view it has a series structure, which means that all four subsystems must work to obtain the required drive function. The SFC, which for reliability considerations is the essential subsystem within the drive, consists of various equipment that functionally interact with each other in a complex manner. The SFC is subdivided into seven assembly levels which, from a reliability standpoint are considered as being independent of each other. The model used is thus quite simple.

The reliability analysis is carried out on the assumption that the VSDS is a system with simple structures, i.e. that its subsystems and assemblies can be expressed with independent elements in the reliability block diagram. From the reliability point of view these elements are assumed to be either connected in series or, if redundant and repairable, connected in parallel. Elements are considered in series if the failure of any one component causes system failure. Elements are considered in parallel if either component can ensure successful operation. In this context a component is understood as an entity in the system which is not subdivided further for purpose of reliability consideration. The series and parallel structures are successively reduced to equivalent components. The VSDS's subsystems and the assemblies of the SFC, as shown in Fig. 3, are treated as components according to this understanding.

The failure rates of the assemblies are obtained by more detailed analysis of their internal structure from the failure rates of the elements down to the component level. The sources from which the component failure rates were compiled are:

- The manufacturer's data for their assemblies and components and also, for example the MIL HAND BOOK.
- The manufacturer's experience with the control devices and the field data for the power thyristors.
- In part the IEEE Standard 500 [1].

All the data are adjusted according to the influence of component loading parameters and to the field experience.

VII. METHOD OF CALCULATION

For successive reduction of the reliability structure to equivalent elements, the following equations have been applied to calculate the respective resultant failure rate on each level:

(1) For series structure with n components:

$$\lambda = \lambda_1 + \ldots\ldots \lambda_i + \ldots\ldots \lambda_n$$

where: λ_i = failure rate of component i
λ = resultant failure rate of serial set

The series structure is correct if the failure of any of the n components leads to a disruption of the operation. This assumption is quite conservative, since certain component failure modes may not cause a system failure, or not in every case. Calculations based on a series structure therefore result in a "worst case" prediction. A typical example of such a structure is the converter control unit, for which the failure of any plug-in module is assumed to lead to a drive trip.

(2) Parallel redundant structure with two identical components, **repairable** during operation:

$$\lambda = \frac{2 \cdot \lambda_0^2 \cdot \mathrm{MTTR}_0}{1 + 2 \cdot \lambda_0 \cdot \mathrm{MTTR}_0}$$

where: λ_0 = failure rate of one component [1/h]
MTTR_0 = mean time to repair of one component [h]
λ = resultant failure rate of the parallel set [1/h]

As a failed component may be repaired any time without shutting down, no additional delay to the actual MTTR_0 is required for redundancy restoration. The pump set in the cooling unit is a typical example of this structure.

(3) Parallel redundant structure with two identical components, **non-repairable** during operation but for which redundancy is checked once per maintenance interval TM (restoration delay) and restored if necessary:

$$\lambda = \frac{-\ln\left[e^{-\lambda_0 \mathrm{TM}}\left(2 - e^{-\lambda_0 \mathrm{TM}}\right)\right]}{\mathrm{TM}}$$

where: λ_0 = failure rate of one component [1/h]
TM = Restoration delay [h]
λ = resultant failure rate of the parallel set [1/h]

As a failed component cannot be repaired without stopping operation, a delay to the next scheduled maintenance stop is required. This time for redundancy restoration, TM at the most, will add to the actual MTTR_0. The cooling fans of the static excitation assembly is a typical example of a "non-repairable" structure.

(4) Parallel redundant r-out-of-n structure for which redundancy cannot be restored during operation:

$$\lambda = \frac{-\ln\left[\sum_{i=r}^{n}\binom{n}{i}p^i \cdot (1-p)^{n-i}\right]}{TM}$$

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where: $p = e^{-\lambda o^{*}TM}$ is the reliability of one component
with: λ_0 = failure rate of each component [1/h]
TM = Restoration delay [h]
λ = resultant failure rate of the redundant set [1/h]

For this r-out-of-n structure, at least r components must work, in order to have an operable system. As a failed component cannot be repaired without stopping operation, a delay to the next scheduled maintenance stop is required. This time for redundancy restoration, TM at the most, will add to the actual $MTTR_0$. An example of this type of redundancy is the thyristor arrangement within the converter legs.

Evaluating the equations for the resultant failure rates λ of redundant structures, as a function of the restoration time (T) of the lost redundancy, leads to the following conclusions:

- Structures according to (2) are uncritical because redundancy can be restored at any short time after the alarm for redundancy loss. If the redundancy would be restored immediately after the indication of its loss, then the restoration time T would be equal to the mean time to repair $MTTR_0$ of the component in question. In this case, if the failure rate λ_0 of the component is, for example, 1000 FIT and the repair time < 10 hours, then the failure rate λ of the redundant set would be 0.02 FIT. This failure rate of such a redundant structure is so low, that it can be entered as λ=0 in the reliability calculations.

- Structures according to (3) can become critical because, in general, redundancy can only be restored during the next scheduled drive shutdown which is long enough, for example TM for preventive maintenance. However, these redundancy structures are also uncritical if the lost redundancy is restored in due course, on a time directed, condition initiated base, i.e. in a very short time (T) compared to the MTBF of the failed component. In this case, if the failure rate λ_0 of one component is, for example, again 1000 FIT and the restoration time < 2 weeks, then the failure rate λ of the redundant set would still be reduced to 0.336 FIT.

- Structures according to (4) could also become critical when the redundancy could only be restored during the next scheduled drive shutdown. However, this redundancy structure is also uncritical if the lost redundancy is restored in due course, i.e. in a very short time (T) compared to the MTBF of the failed component. In this case, if the failure rate λ_0 of one thyristor level is, for example, 100 FIT and the restoration time is shorter than or equal to 2 weeks, then the failure rate λ of one converter leg is 0.02 FIT for a 3-out-of-4 redundancy structure. This also means that a thyristor set of a 24 leg converter can still be approximated with λ=0 in the reliability calculations.

VIII. THE VALUE OF RAM FIGURES

How should the value of the reliability figures be judged ?

The reliability figures have to be used with great caution when it comes to interpreting their value. This is particularly true when there are not sufficient systems of similar design in operation on which the figures can be based.

In this context one has to distinguish between estimated and predicted reliability. The predicted reliability is analytically calculated for the system structure in question, while the estimated reliability is based on statistical information available for the installed base of similar systems.

One must be aware of the limitations of the calculated or predicted reliability method. Predicting reliability in terms of calculated MTBF alone, without any cross-check with field experience records, would be of no great value. This is because of the wide spread of component failure rates (up to more than 1,000 times difference between the low and high figures occur), issued for the purpose of calculation. So it is obvious that the field experience plays a very important role in the final reliability and availability appraisal.

When field experience is used to correct the figures of the calculated drive reliability, it is generally found that the calculated figures are quite conservative. The correction is done by multiplying the calculated figure with the field experience factor. A field experience factor of about two for the SFC is not uncommon.

However, the results of reliability calculations provide very valuable information when comparing alternative designs or when studying the impact of different redundancy configurations on the system reliability, prior to design and operation.

IX. EXAMPLES

What has been discussed so far is now illustrated in a practical example. The figures of interest are the calculated system reliability data namely: Failure rates and MTBF as they result from the RAM-analysis.

The influence of redundancy and maintenance strategy is looked at in the following example. The analysis is performed on a 20-30 MW compressor drive with a 2-pole motor. In Table I can be found the data for the drive with a **standard** 12/12-pulse (24 legs), water cooled LCI converter with 3 thyristors in series per leg (no redundancy).

As can be seen, the focus has to be on the power section, control, cooling unit, low voltage distribution and the excitation. The other items in fact have very little influence on the total reliability. The motor MTBF is calculated from the

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installed base of motors of this design, however not only LCI motors.

TABLE I

THE RELEVANT MTBF FIGURES FOR A STANDARD LCI DRIVE

Part	Failure rate (FIT) rounded	MTBF (years) rounded
Power section complete (N=3)	8800	13
Control	6400	18
Cooling unit	5400	21
Interfaces	260	445
Low voltage distribution	3200	36
Static Excitation	2500	45
DC link reactor	10	11415
Complete Converter	26570	4.3
Complete Motor	5000	23
Complete Transformer	540	210
Circuit breaker	70	1630
Complete Drive System	32180	3.6

Redundancy concepts are available as standard options for thyristors and cooling pumps, while a redundant control or redundant excitation system normally are not standard. A redundant control does not bring as much increased reliability as one would think. This for two reasons: One is that the system will need an additional changeover logic that has to determine which of the controls that should be used. The other reason is that control is getting more and more reliable.

Table II displays data for a drive with a 20-30 MW 12/12-pulse, water-cooled LCI converter, **customized** with different redundancies: 3-out-of-4 series thyristors per leg and alternatively 3-out-of-5 per leg.

TABLE II

MTBF BY USE OF REDUNDANCY - NO MAINTENANCE

	MTBF subassembly		MTBF compl. drive	
	[years]	[%]	[years]	[%]
Description				
No red. thyristor (N=3)	13	100	3.6	100
1 red. thyristor (N=3+1)	40	313	4.4	123
2 red. thyristors (N=3+2)	52	404	4.5	126
No red. cooling pump	21	100	3.6	100
Redundant cooling pump	25	121	3.7	103
Red. cooling pump & N=3+1			4.6	128
Red. control & excitation			4.0	111
Redundant converter			6.5	185
Redundant motor			4.3	121

It is, however, not realistic to calculate without maintenance/ restoration of lost redundancy. All systems will get maintained at some point in time. A major message in this paper is the fact that restoring the lost redundancy has a great influence on the reliability of redundant equipment.

The impact of the restoration delay of lost redundancy can be illustrated in a graph (Fig 4). Without restoration, the MTBF for the set of thyristors would be 94 years and with a restoration delay of 2 years after a loss of redundancy, this would raise to about 5000 years. However when the drive system MTBF is calculated, the increase is only 0.2 years.

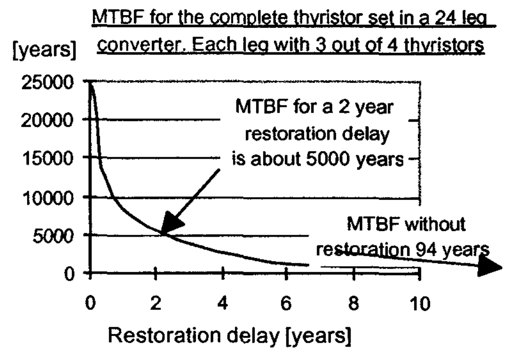

Fig. 4. The restoration delay impact on thyristor MTBF

It is fair to say, that if the equipment is maintained every 1-2 year, the impact of failing thyristors can be disregarded. Even if in the above case, the MTBF of the thyristor set is increased to 10000 years by a yearly maintenance, other remaining components of the power section such as the cabling, the PTs and CTs, would emerge as the bottlenecks and limit its MTBF to about 70 years. Similar considerations can be made for every other assembly level of the drive system.

One preferred way to overcome these bottlenecks is by-passing them with higher level of redundancy (Ref. to 0. XI. REDUNDANCIES).

The importance of thyristor redundancy and at the same time the importance of quick restoration of a lost redundancy is well understood by looking at figure 5, that deals with m-out-of N redundancy. The following three statements can be made: 1)The more thyristors per leg, the higher the impact of redundancy. 2) The higher the FIT per thyristor position, the higher the impact of redundancy. 3) The more thyristors per leg, the more important it is to quickly restore the lost redundancy in order to maintain a high availability.

If the extremes (one thyristor respectively 12 per leg) are looked at the effects of thyristor redundancy becomes obvious.

In the case of only one necessary thyristor per leg, another, redundant thyristor, will only raise the MTBF by some 8%, whereas in the case of 12 thyristors, the MTBF of the drive system would be reduced to 50% without a redundant thyristor. It can also bee seen that, in the case of m=12, the

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total drive MTBF would be less than for a drive that requires only one thyristor per leg, if the loss of redundancy is not restored within a relatively short time (< 1 year).

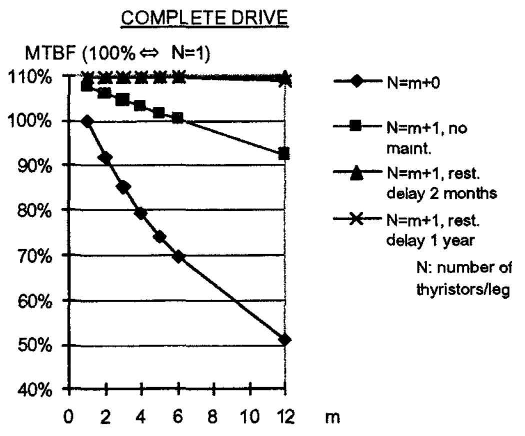

Fig. 5. Redundancy and restoration impact on drive system.

X. RAM ENGINEERING

RAM engineering is the process of creating and preserving reliability with the purpose of keeping availability up on a *high level [2]. It is a process that lasts from tendering to* customer acceptance and beyond. Some of the RAM engineering actions influence reliability and some others the availability more (Ref. to Fig. 6).

Reliability ⇓ (Create)	Availability ⇓ (Preserve)
• Quality	• Maintenance
• Margin in design	• Diagnostics
• Simplicity	• Ease of repair
• Redundancy	• Available spare parts
• Work tests	• Training
• (Burn-in)	• Documentation
	• System redundancy

Fig. 6. Creating and preserving reliability/availability

High reliability is **created** by improving the quality of the design and of the components and by applying redundancy. The user and the supplier must work together closely to create VSDS reliability. Already at the planning stage of the drive project they have to get onto the subject of reliability issues and outline a common view for reliability requirements and specifications as well as for any redundancy strategy.

High availability is **preserved** by taking measures to maintain the built in reliability and by ensuring a short time to clear a fault. Both the VSDS manufacturer and the user *can contribute to this. The manufacturer by taking design* measures for good maintainability and ease of repair and also providing good documentation. The user can contribute with site specific arrangements such as: maintenance *strategy, keeping skilled maintenance personnel trained* and by holding all recommended spare parts in stock. An alternative would be to have a service contract with the drive supplier.

XI. REDUNDANCIES

When VSDSs are used in applications where extremely high reliability and availability are mandatory and/or where there are operational restrictions for maintenance, and the reliability of the standard drive doesn't meet with the requirements, extra reliability can be designed and built with a suitable redundancy. Redundancy is the provision of standby equipment that will take over should the primary equipment fail. It can improve availability dramatically, provided of course that the back-up equipment is functional at the time of changeover and that the failed equipment can be repaired quickly.

Different **levels of redundancy** are practicable. If one looks up redundancy concepts in technical literature one will come across many proposed and implemented solutions. The levels range from single component redundancy up to completely redundant VSDSs. In general, standard VSDSs are prepared for the implementation of several redundancy concepts and the equipment required is, to some extent, available as prepared options or can be engineered optionally. The most common levels are:

- Redundant drives (Ref. to Fig. 7). It is quite obvious that this is the redundancy level with the best fault coverage. The flying spare can take over the function of one failed drive at any time. In this case the change-over to the standby drive is preferably initiated on the level of process control.
- Redundant drive subsystems, normally a common spare converter/transformer package, is a transparent and simple solution.
- Redundancy in the SFC configuration. This redundancy concept is attained by splitting up the converter power part into two identical and individually controlled, parallel channels. This type of redundancy has a lot of drawbacks, one being the limitation to 50% of rated power at rated speed when operating only on one channel.

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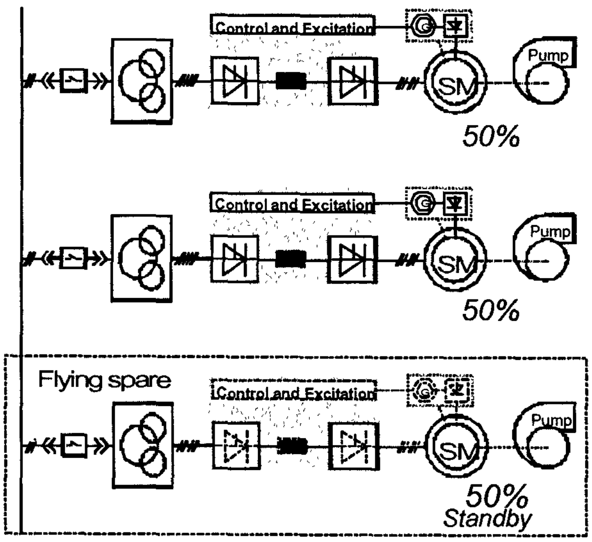

Fig. 7. Common spare drive system

- Redundant SFC assemblies. This category concerns in the first line complex converter parts that influence the drive reliability, for example, a redundant, fault-tolerant control and excitation. Because of the increased reliability in the controls mainly due to higher density of functions, this type of redundancy has been more applied in the past than one can expect to see in the future.
- Redundancy of individual SFC devices/components such as power semiconductors and parts subject to wear, for example, pumps and ventilation fans. Series redundancy in the thyristor stacks allows uninterruptible continued drive operation until the next planned outage, also when single thyristor levels have failed. With continuous monitoring, the most suitable time for restoring lost redundancy can be determined. Any r-out-of-n redundancy of the thyristor levels in all the converter legs are de facto realized in hot and non-repairable structure. But if lost redundancy can be restored by a relatively short-termed corrective mainte-nance during a normal drive stoppage, this type of redundancy may be treated, from a reliability point of view, as **pseudo repairable** in operation. All redundancies introduced in the SFC are realized in such a way that the drive system has a fault-tolerant behavior in respect to a deficiency of any redundant component. A singular hardware failure of any one redundant component will neither lead to a forced outage of the drive system nor to any functional restriction or transient disturbance.

MTBF and availability of the VSDS are increased the most, if complete drive systems, the subsystems of which are preferably manufactured as standard units, can be kept as complete stand-by equipment and if the corresponding concepts allow for "in operation repair". As one example see Fig. 7 (installed capacity 2*50%+50% redundancy).

XII. RCM: RELIABILITY-CENTERED MAINTENANCE

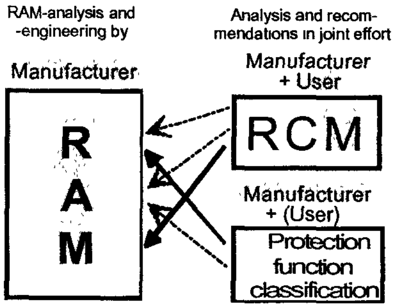

Fig. 8. The RCM influences RAM

RAM Engineering in the widest sense, is a process that lasts from tendering to customer acceptance and well beyond. The optimization of RAM that takes place with the process owner and a manufacturer is therefore very useful, especially if the user repeatedly buys VSDSs and can input his previous experience. This optimizing process can profit from the use of consultant companies that serve as facilitators in the so-called RCM (Reliability-Centered Maintenance) action (Ref. to [3], [4]). The RCM action is a methodology for analyzing complex systems and revising their design and maintenance with the purpose to increase system reliability and availability. RCM should, so to speak, check and confirm the RAM results and detect weak points if there are any. Currently process owners show a great deal of interest in RCM. They use the procedures for planning the maintenance strategy of their plants and the methods are just as well suited to be applied to VSDSs. One category of functions, namely the drive's protection, requires special attention. This because of the contradictory requirements of safety and reliability. Safety requirements are compulsory and one could think that the solution is an extensive protection. However, every extra function that is added also increases the risk of unnecessary trips. A separate analysis with the special purpose to identify and clearly understand the potentially superfluous protection functions or/and any unsuitable protection equipment is recommended. Such an analysis can be an extension or a part of the RCM study. (Ref. to Fig. 8)

A RCM Objectives and Methods

In the widest sense RCM as it was applied here to VSDSs is the process used to determine what must be done to ensure that the drive continues to fulfill its intended functions in its present operating context.

The final target is thus to preserve the VSDS function. Main intermediate objectives of the RCM action are:
- Identification of critical equipment and failure modes that potentially impact on drive availability.
- Recommendation of preventive maintenance tasks to minimize the risk and effect of potential failures.

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One outcome of the RCM, and one which is of special importance with large VSDSs, is the clarification of the need for any redundancy.

The RCM methods bring together technical and economical points of view. The expected ultimate benefits out of the RCM exercise are both reduction in maintenance expense and increased drive availability.

The methodology underlying the RCM action has similarities with the methods used for RAM analysis (Ref. to "0. VI. METHOD OF ANALYSIS ") however without having to go to the reliability block diagram. The steps in the RCM exercise are:

- Definition of the SFC for analysis
- Decomposition of its functional structure in a 'top down' approach
- Definition of intended functions of the subsystem and assembly levels
- Application of FMEA (Failure Mode and Effect Analysis) on assemblies and where necessary on components
- Identification of failure consequences (hidden, safety, operational)
- Definition and proposal of corrective actions (maintenance/ (re)design/spares)

There is a need for close collaboration between user and manufacturer when going through these steps.

The final result of the RCM exercise has to be the realization of the necessary corrective actions that should be taken.

B. Obtained results

In 1996 an RCM study was done in joint effort between a large drives user, a manufacturer and a facilitator. The protection issues were taken care of by using IPF exercise (Instrument Protective Functions). IPF is a user-defined method for classifying and evaluating all the drive protections. The teams carrying out these activities were composed of supplier's and user's specialists that brought in design and manufacturing experience, respectively feedback from maintenance and operation. RCM and IPF results are reported in [5] and [6]

The scope of the RCM and the IPF exercises covered a SFC control of a motor with 18 MW shaft power. The converter is a standard converter of the same type as the one referred to in section 0. IX. EXAMPLES. It is designed in a 12/12 pulse configuration, has water cooling and is built with 3 series connected thyristors per branch and without any redundancy.

The main objectives of the RCM exercise were (1) to identify critical SFC equipment, (2) identify failure modes that could impact the drive availability, (3) propose specific measures to further improve the drive system reliability and (4) to recommend further preventive and predictive maintenance tasks to minimize the risk of a forced drive outage.

The main objectives of the IPF classification were (1) to find a justifiable optimum between fail-safe requirements and drive reliability (freedom from danger and injury and avoidance of overprotection which could potentially lead to spurious trips) and (2) to check whether the integration of protective functions into the digital controller was in agreement with the safety standards applied by the user.

The ultimate goal of both exercises was to figure out whether the current standard SFC design could achieve the user RAM requirements, namely:

- A planned availability of 0.997 (with continuous operation for 4 years and mean time to repair of 80 hours)
- A reliability R of > 0.78 (failure probability 1-R < 0.22) in the 1 year period and mean time to repair of 48 hours

The outcome of the study confirmed that the SFC in its standard design is sound. It was also established that with a minimum level of redundancy, (i.e. 3-out-of-4 thyristors and redundant cooling pump) it is realistic to expect RAM figures as mentioned above.

Various maintenance items were found, covering the areas of stock-keeping, preventive, predictive, and corrective maintenance. Some examples of these are: Keep matched thyristors in stock, regular replacement of cooling water pumps, infra-red thermography for early detection of loose high current connections and the need to have the necessary special tools at hand. Some of the design items as, for example, efficient labeling for improving the MTTR, were implemented right away. Others for which there was not yet a readily available solution (e.g. limited life time excitation cooling fan) were listed for implementation in the next redesign.

The outcome of the IPF classification made it clear that some of the trip initiators can be replaced by an alarm. Others can be deleted completely, since they were superfluous. Both leading to an overall increase in the drive reliability. Another finding was that a further increase in the reliability can be achieved by implementing more of the protective functions in the drives controller. The controller, however, has to meet the safety standards applied by the user.

The fact that the specialists from the user and the manufacturer spent time round the same table analyzing and discussing the drive's structure and functions, led to a good common understanding of the failure modes and their influence on reliability mainly from the maintenance point of view. This exercise was successful not least because of the good facilitation based on an efficient methodology.

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XIII. ECONOMY

Here an attempt is made to answer the question: "how much does increased reliability cost ?" An increase in calculated MTBF is given a dollar value expressed as a percentage of the cost of a standard drive.

The example of the 20-30 MW compressor drive is used once again. For the cost comparison, 100% represents the motor, the SFC, the H.V. transformer, the M.V. switchgear, the power factor compensation and the harmonic filtering. A typical cost distribution of the above is:

Motor only	= 33%
Converter only	= 27%
Transformer only	= 16%
Switchgears & auxiliaries, erection etc.	= 24%

The calculated reliability of the system without any redundancy can be seen in Table I. With this table as starting point, one can find out how much it would cost to get increased reliability. The focus has to be on the power section, control, cooling unit and the excitation. The other items in fact have very little influence on the total reliability.

TABLE III
THE COST OF REDUNDANCY AND CORRESPONDING INCREASE IN MTBF OF THE COMPLETE DRIVE.

Description of redundancy used	Cost In-creas e%	MTBF increase % No mainte-nance	1 year main-tenance interval	On demand restored lost red
Redundant thyristor (3+1)	1.5	23	29	29
Ditto plus redundant cooling pump	1.7	33	34	35
Redundant converter	27	38	203	475
Flying spare	100	50	335	9000

Please keep in mind, that the cost in Table III is in relation to the cost of the electric drive system. If the cost of the total installation, including the driven equipment, civil works etc. is used as basis for comparison, the figures are much lower. It depends on the type of application, but one can expect that the percentages are at least halved.

The conclusion that can be drawn is, that if a drive is expected to be operational continuously for 2-4 years, it is only macro redundancy, like an extra drive or an extra converter, that will offer the calculated reliability that is high enough to ensure such an application. If the drive can be shut down in a scheduled manner at any time in order to replace a lost redundancy, sufficient reliability may be obtained by including part redundancies like: pumps, fans, thyristors etc. (Ref. to "0. VII. METHOD OF CALCULATION " and "0. IX. EXAMPLES").

XIV. FIELD EXPERIENCE

The field experience is illustrated with two case studies of LCI drives and with an account of the outage statistics of a large number of LCIs.

A 3000 rpm / 3.4 MW Boiler Feed Pump Drives

In 1986 the owner of an existing nuclear power plant ordered two 3000 rpm / 3.4 MW 12/12 pulse LCI VSDSs (transformer, converter and motor) to drive two existing boiler feed pumps. The new LCI drives had to replace two out of three 15 year old sub-synchronous Cascade drives. The third Cascade drive was kept to be used as a flying spare. Thus the resulting VSDS capacity is 3*50% (see Fig. 7).

The 3*50% VSDS-capacity concept allowed to design the drive subsystems as standard units, without any built-in redundancies. The standard converter has an air-cooled 12/12-pulse power section, a static excitation and low voltage distribution cubicle and a control cubicle. (see Fig. 9).

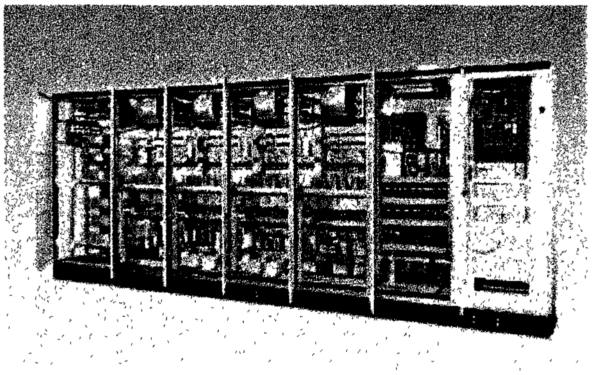

Fig. 9. 12/12-pulse, 3.4 MW, air-cooled LCI converter

During the commissioning in 1987 extensive tests had to prove the voltage-dip ride through capability of the LCI VSDSs in case of main and auxiliary supply voltage dips and the successful changeover to the stand-by VSDS in case of a trip of one of the main drives.

Since the commissioning of the two LCI VSDSs, the yearly preventive maintenance - carried out by the supplier during the scheduled outage of the power plant - helped to preserve the high availability of the VSDSs. Within the cumulated operation time of approx. 18 years, only one trip (failure of a PCB component) of one of the main VSDSs has been reported. Due to the redundant drive, this failure did not cause a power plant trip.

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B. 1500 rpm / 6.3 MW Compressor Drive

In 1991 the owner of an existing petrochemical plant ordered one 1500 rpm / 6.3 MW / 12/12-pulse LCI VSDS (transformer, converter and motor) to drive a new wet gas compressor. The new system replaced a steam turbine drive dating from the 1950's. The reasons for the replacement were environmental requirements and high maintenance costs.

The VSDS was customized in close cooperation between the supplier and the process owner:

- In order to reach the high RAM requirements, the water cooled converter was built using standard options, namely 2-out-of-3 thyristor redundancy, redundant pump, heat exchanger and instrumentation in the water cooling unit and a redundant speed measuring.
- A container solution was selected to achieve a quick replacement. The container (see Fig. 10) houses: the water cooled converter, the control electronics, a Motor Control Center (MCC), an uninterruptabel power supply (UPS), a redundant air conditioning system and a fire alarm system.

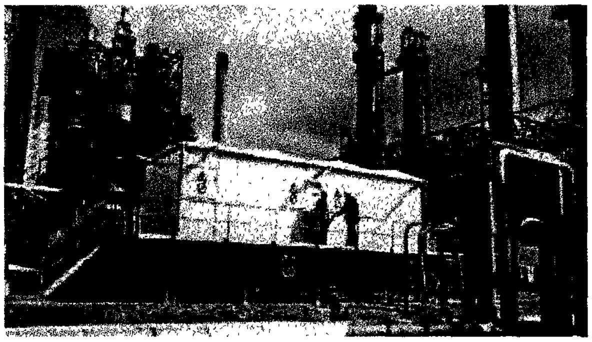

Fig. 10. LCI VSDS Container for a Gas Compressor 6.4 MW

In order to ensure that everything would properly work directly after the installation, the customer asked - in addition to the standard factory tests of transformer, converter and motor - for a combined test of the complete VSDS with full load and a string test with the compressor.

Since the successful commissioning in 1993, one trip (overcurrent) of the VSDS has been reported.

C. Cumulated Outage Statistics

Field experience data based on some hundred installed LCI systems (both drives and starting systems) delivered and commissioned since 1984 are available. Because circuit breakers, transformers and synchronous motors are well known components, that have already been in use for a long time and in a lot of other applications, and since they also are not dominant in the calculation of the complete VSDS's MTBF (see Table I), the field experience, described below, is restricted to the static frequency converters (SFCs) only.

At the beginning of 1998, all the commissioned SFCs with a cumulated power of approx. 1500 MW (the smallest being 1 MW and the largest 101 MW) had a total operating time of some 1300 years. Process owners and local service organizations reported a total of 52 failures, resulting in an actual MTBF of 25 years. Assuming that only every third failure is reported, the actual MTBF is 8 years, a value that is still two times better than the calculated MTBF of approx. 4 years (see Table I). This comparison between the calculated and the actual MTBF of the SFC points out that both the series system structure taken as basis for the reliability analysis and the failure rates assumed for the components are very conservative.

XV. CONCLUSIONS

In terms of reliability performance, the customer must be aware that he might not get what he thinks he specified - he might get what the supplier thinks that he has specified, i.e. it is extremely important that the customer and the supplier have the same understanding.

MTBF and other reliability figures should be used with care. They are relevant when comparing different layouts in the same drive. They can hardly be used to rank reliability between different suppliers. They can be used to compare two different systems, if the comparison is made by the same company/person that has used a uniform approach in both cases.

The value of redundancy has to be evaluated in the light of the service and maintenance that is planned or that is possible to be used. A drive with a requirement to operate for 3-4 years without a shut-down, be it scheduled or unscheduled needs a redundancy on the macro level, i.e. a complete drive or redundant converter.

Again it has to be said, that the best result will come out of a close discussion between the supplier and the customer.

[1] IEEE Std 500, Guide to the collection and presentation of electrical,electronic and sensing component reliability data for nuclear- power generatting stations.

[2] Kobi H., Terens L. and Wikström P., 1998 "Reliability, Interfacing and Standardization Aspects in High Power AC Drive Applications", Proceedings of the IPC conference 1998.

[3] Moubray J. Reliability-centred Maintenance, Butterworth-Heinemann Ltd, Oxford (1991)

[4] Smith A.M. Reliability-Centered Maintenance, McGraw -Hill Inc. (1993)

[5] Reliability Centered Maintenance RCM on a Load Commutated Inverter LCI for an electric drive. KEMA NUCLEARRegistered Document 41184-NUC 96-4369, Author: H.C.Wels

[6] IPF Classification on a Load Commutated Inverter for an electric drive. A Shell registered document, 18 Oct. 1996, Authors P. Zimmermann and L.Korteweg

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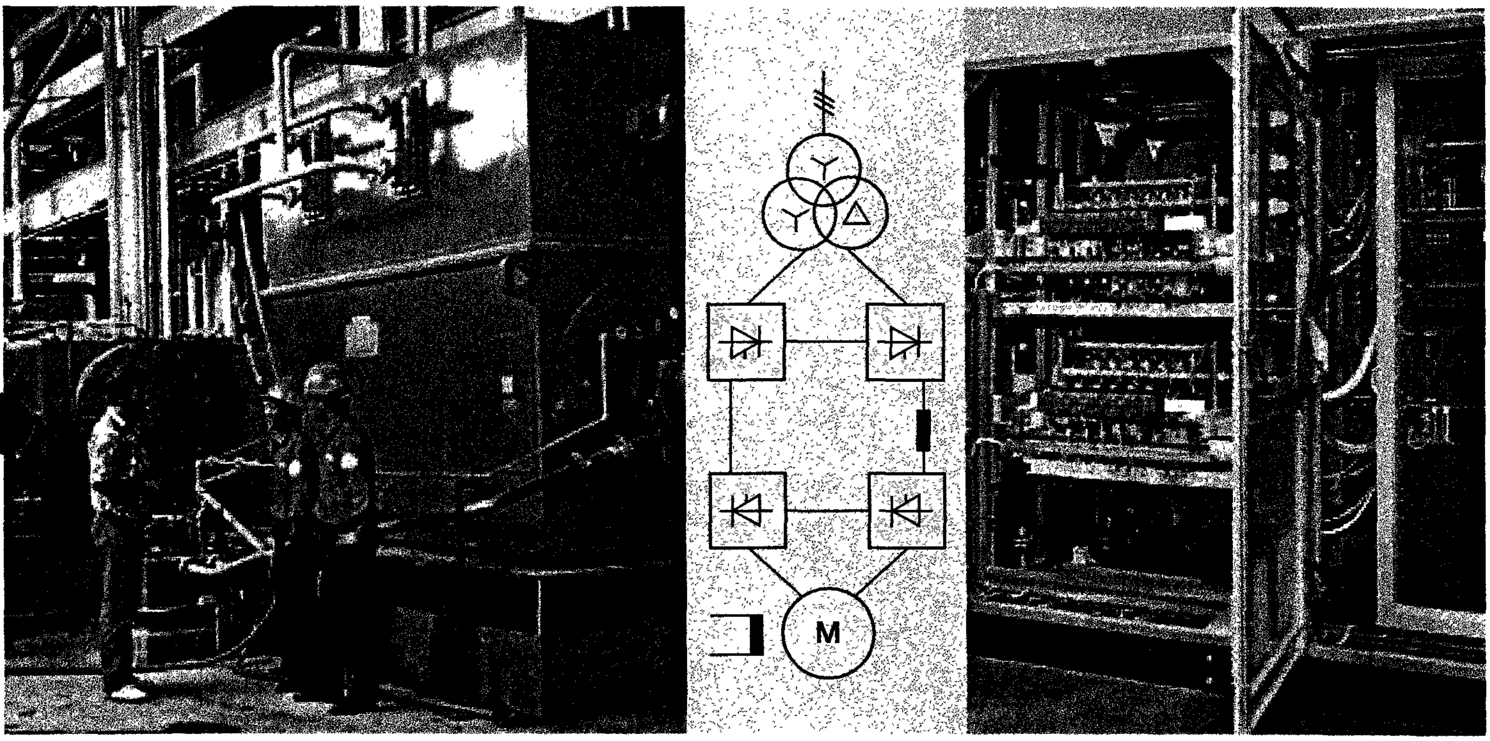
MEGADRIVE-LCI

Large adjustable-speed synchronous motor drives

Power range 2000 ... 80000 kW



ABB

IP7_025311

Large adjustable speed AC drives designed to raise your profitability

You would be surprised how many industrial processes can be improved by using adjustable speed electric motors. The larger the process and the higher the performance demands, the greater the benefits from electronic speed control. The energy savings alone in a drive of a few megawatts can offset the cost of the speed control system in just months or a few years.

Processes and industries
- **power plants**
- **chemicals and petrochemicals**
- **building materials**
- **metals**
- **mining**
- **research and development**
- **water and sewage treatment**
- **marine and offshore**
- **oil and gas**
- **pulp and paper**

Reasons for using MEGADRIVE-LCI

Efficiency
- Compressors, fans and pumps run at their optimum operating point.
- Substantial energy savings

Reliability
- Mechanical flow control devices as potential source of failures are eliminated.
- "Softer" control reduces wear on motor and driven plant.

Maintenance
- Less stress and wear reduces the maintenance requirement.
- Mean time to repair typically <1 hour

Typical applications

Speed control and soft starting of
- **fans and pumps**
- **high-speed compressors**
- **reciprocating compressors**
- **wind tunnel blowers**
- **blast furnace blowers**
- **rolling mills**
- **extruders**
- **marine propulsion systems**
- **test bays**

Emissions
- Electric drives avoid emissions (a significant advantage in today's world).
- Noise reduced to the minimum possible.

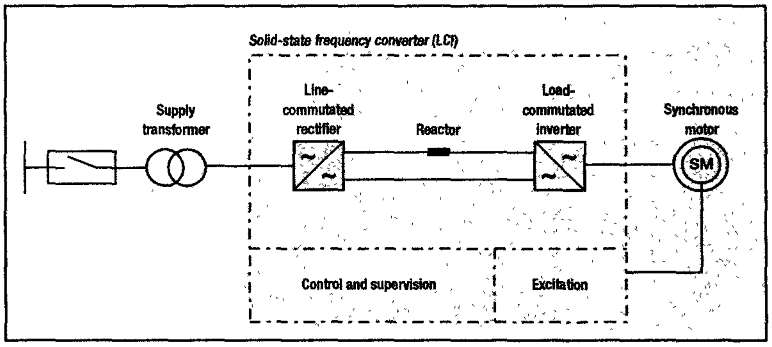
Better process control
- greater accuracy
- smooth control at low flow rates
- wider range of control
- faster response with greater stability
- reduced production waste and higher quality
- set-points quickly reached and therefore shorter production times
- renowned reliability and adaptability

Soft starting
- less mechanical stress on motor and driven plant
- minimum repercussions on the supply system
- reduced temperature rise while the motor is accelerating
- no need of pony motors and clutches
- starting of very large motors and generators

Substantial savings of energy and maintenance costs

Smoother running results in
- **higher productivity**
- **longer plant life**

The main components of an adjustable speed drive are shown in the diagram to the right. Although the transformer and the motor are designed for operation in conjunction with a converter, they do not differ essentially from normal versions. The following explanation is therefore confined to the components of the frequency converter and its operation.



Rectifier

The rectifier is of the controlled line-commutated type similar to those used for DC drives. The rectifier or supply converter in conjunction with the reactor in the DC link circuit form a fully controllable DC current source.

DC link reactor

The reactor in the DC link circuit smoothes the DC current and limits the rate of current rise in the DC link circuit in the event of a fault.

Inverter

Thyristors in the inverter electronically switch the DC current such as to produce a three-phase AC system of variable frequency and voltage for supplying the motor. The design of the inverter is basically the same as that of the rectifier with the exception that the inverter phase currents are commutated by the motor voltage. An inverter of this type is referred to as a load-commutated inverter (LCI). At very low speeds (0...5% of rated speed), the motor voltage is too low to guarantee reliable commutation and pulse mode commutation has to be employed.

Excitation

The excitation of the synchronous machine can be of the brushless or slipring type. It provides the field current over the entire speed range and at standstill.

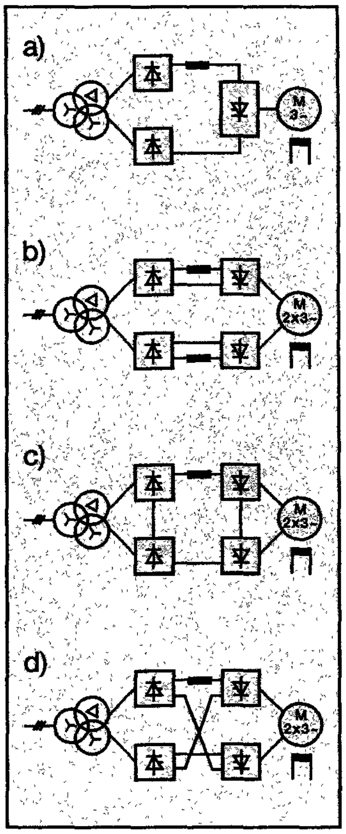
Control system

The main purpose of the control system is to generate the firing impulses for the thyristors in the rectifier and inverter at the right instants to maintain the desired voltage and frequency across the motor. Since the drive system is self-controlled, it cannot fall out-of-step. The principal applied is that of a four-quadrant drive which permits driving and braking in both directions. Voltage, current and speed are regulated by closed-loop control.

12-pulse circuit

To minimise both the harmonic influence of the drive on the supply system and the ripple on the motor torque, rectifier and inverter normally operate in a 12-pulse mode. This technique eliminates harmonics of the series 5th, 7th, 17th and 19th etc. A synchronous motor for this kind of operation is equipped with two sets of windings electrically displaced by 30°. Similarly, the supply transformer also has two secondary windings shifted by 30°.

The diagram to the right shows a simplified 6-pulse circuit a) and alternative 12-pulse circuits b), c) and d). The best one to use for a particular application is largely determined by the power and voltage ratings of the drive.



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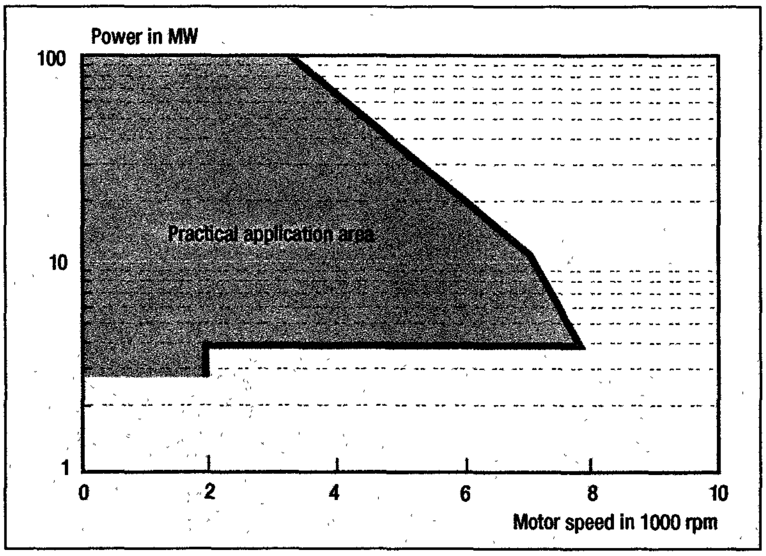
Power and speed range



The permissible relationships between power and maximum speed for MEGADRIVE-LCI. The maximum speed is primarily determined by the design of the motor, i.e. by the physical forces to which the rotor is subjected.

Technical data

Typical power range: **2...80 MW**
Speed control range: **(0)...10...100%**
Motor frequency: **0...125 Hz**

The maximum speed is a function of the number of poles, e.g. two-pole machines have a maximum speed of 7500 rpm.

World-wide references

ABB has installed more than 150 MEGADRIVE-LCI units with a total power of 1140 MW for applications in power plants, the oil, gas and chemical industries, in water pumping stations and in test bays. For the most part, they are driving compressors, blowers, pumps and extruders efficiently and reliably under extremely adverse ambient conditions (corrosive atmospheres) or in hazardous areas (oil platforms etc.).
The largest drives supplied up to the present were for a hydroelectric power plant in the PR of China (pump rated at 60 MW) and for the Troll project in Norway, where five compressor drives each with a rating of 41 MW and a maximum speed of 3750 rpm are installed to transport natural gas. Another noteworthy project was for a converter-fed high-speed synchronous motor (14 MW at 6400 rpm) to replace a steam turbine driving a five-stage compressor in an ethylene production plant in Italy.
Over 50 of the units supplied for driving boiler feed pumps in electricity power plants and operate in the high-speed range up to 6000 rpm. They have ratings between 3 MW and 15 MW.
These together with approximately 360 LCI.ST units supplied for soft start of synchronous machines, make ABB a leading supplier of this kind of drive technology.

Design and function of the MEGADRIVE-LCI control system

Structure

As can be seen from the block diagram below, the control system is divided into three parts for:

- interface modules
- programmable controller
- standard modules

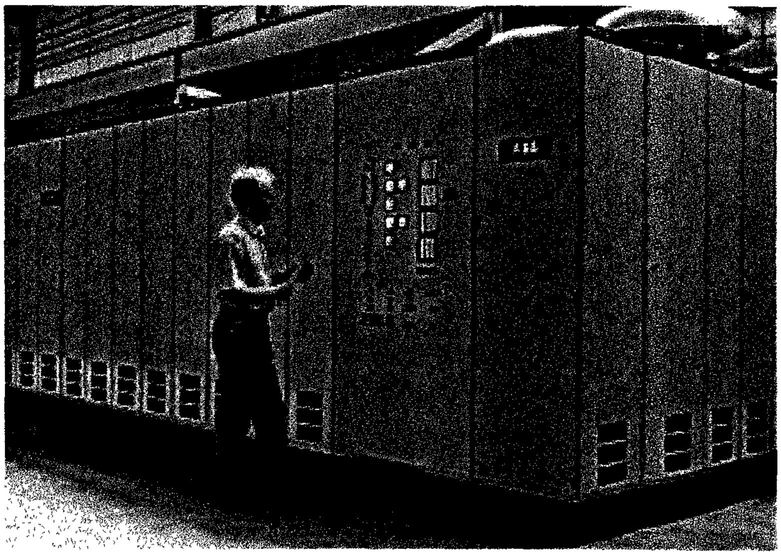
The *interface modules* facilitate the exchange of data with other drive components, remote control from a control room and communication with a higher level control system.

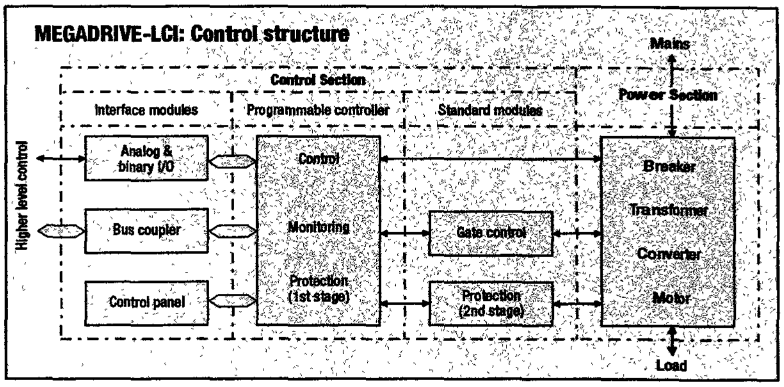
The *programmable controller part* includes the torque and speed controllers, complex protection functions, the sequential control for the starting up and shutting down routines as well as the emergency trip, drive supervision and general diagnostic functions. All these tasks are performed by a high-speed programmable controller which has been specifically designed for large converter fed AC drives. It provides a high degree of flexibility and being programmable is easily adapted to accommodate different drive applications.

The *standard modules* includes the gate control units for the thyristors and hard-wired protection devices which duplicate and serve as back-ups for the protection functions performed by the digital control part.

The functions of the control system are grouped as follows:

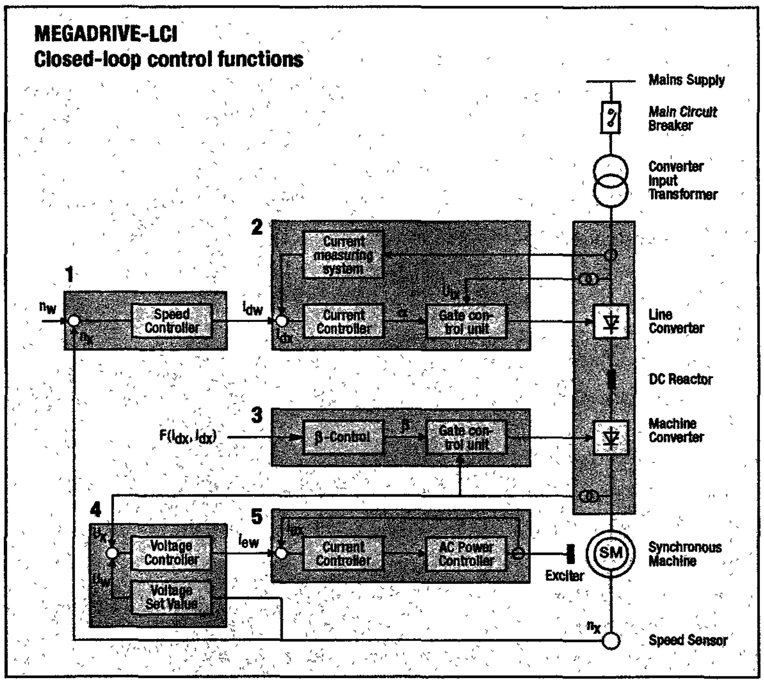
- sequential control
- closed-loop control
- communication and interfaces
- protection, supervision and diagnostics





Sequential control

This part of the control system generates the signals in the correct sequence for starting up and shutting down the drive. The functions are performed in several stages and include intermediate checks for ensuring that start-up, respectively shut-down is proceeding normally and also emergency shut-down routines which are executed in the event of a fault on the drive.



The most important regulation functions of a LCI drive system are the feedback and forward control. They act on the supply converter (rectifier), on the machine converter (inverter) and the excitation system.

Speed controller

The speed controller (1) and the current controller (2) form a conventional cascade feedback circuit. The speed controller provides the current controller with the set-point value necessary to attain and maintain the required speed. It may be assumed that the torque developed by the motor is approximately proportional to the motor current, flux and power factor. Thus the current controller indirectly adjusts the torque exerted on the shaft of the motor by varying the DC voltage at the output of the line converter.

ß angle control

ß angle control (3) is a forward control function which determines the instant of firing of the thyristors in the machine converter. The angle ß is adjusted as a function of current and speed such as to ensure correct commutation of the inverter.

Voltage controller

The voltage controller (4) and the current controller (5) also form a conventional cascade feedback circuit. The voltage controller provides the excitation current controller with the set-point value it needs to attain and maintain the required voltage at the motor terminals. Basically, the motor voltage is adjusted in proportion to the motor speed which is equivalent to maintaining the motor flux at its rated value. The current controller (5) adjusts the current of the brushless exciter by varying its stator voltage via a three-phase AC controller.

Communication and interfaces

The programmable high-speed controller communicates with the other control system modules via a parallel bus capable of transferring the control function data at the required rate. Communication with other units of the drive and with any higher level control system or remote control centres takes place via corresponding interfaces controlling either parallel or fast serial links.

The ability to ride through short supply interruptions is one of the most important features of MEGADRIVE-LCI

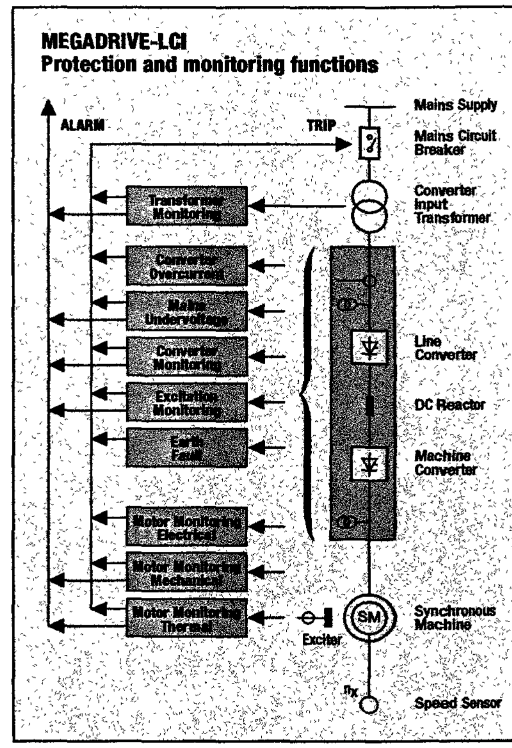
Usually, your process just carries on without noticing anything.

The protection and supervisory functions ensure that the mechanical and thermal operating limits of the drive are not exceeded. They are implemented in the application program running on the microprocessor of the programmable high-speed controller and their signals are evaluated by the diagnostic system. The most important protection functions (overcurrent and overspeed) are also duplicated by hard-wired devices acting as a back-up for the software protection functions. Trips and alarms are transmitted to the relevant devices to shut down or, should it become necessary, trip the drive completely. Faults are displayed in plain language on the control panel in the door of the control cubicle and on any remote control panel with clear indication of the first fault. Numerous protective and supervisory functions are available.
The following are the minimum included with the standard MEGADRIVE-LCI.

Motor:
Overvoltage, undervoltage, stalled rotor, winding and bearing temperatures, overspeed and set speed deviation.

Converter:
Supply over and undervoltage, overcurrent, ground fault, failure of auxiliaries, cooling water temperature, level, flow and conductivity, respectively air flow in the case of air-cooled units, and excitation and control system failure.

Supply transformer:
Oil temperature and level and Buchholz in the case of oil-immersed types, respectively winding temperature in the case of dry types.



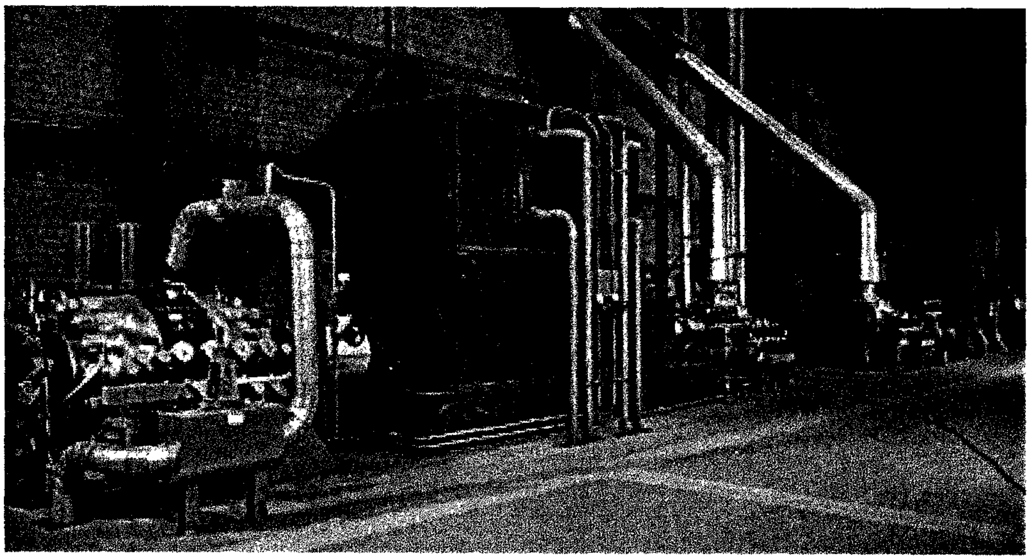
Reliability is a must!

Reliability and availability are of the utmost importance in power plants and industrial processes. As a leading supplier of drive systems, ABB achieves the highest reliability by ensuring that it complies with the quality standards and procedures specified in ISO 9001. Tests are performed at various stages during production in addition to the extensive final tests (heat run, combined, and burn-in tests are conducted on request). Redundancy of crucial components (e.g. cooling pump or fan and essential parts of the control system) can be provided which enormously increases reliability and availability while enabling maintenance intervals to be extended to 4 years and more.

Also components are conservatively rated and more than adequate safety margins are allowed.
Where appropriate, functions are physically isolated from each other in the interest of greater reliability.

A special design feature of MEGADRIVE-LCI is its ability to ride through brief supply interruptions so that in most cases they pass unnoticed by the process. Should the drive fail in spite of all these precautions, fault location and corrective action are made easy by the failure indication system which points to the precise component. Attention has also been paid to the simple replacement of all components, units and assemblies. For example, a thyristor can be replaced without having to interrupt the cooling water circuit. All the measures incorporated should achieve repair times of just minutes and an MTBF of more than 4 years.

Applications



Boiler feed pumps
in a thermal power plant driven by MEGADRIVE-LCI

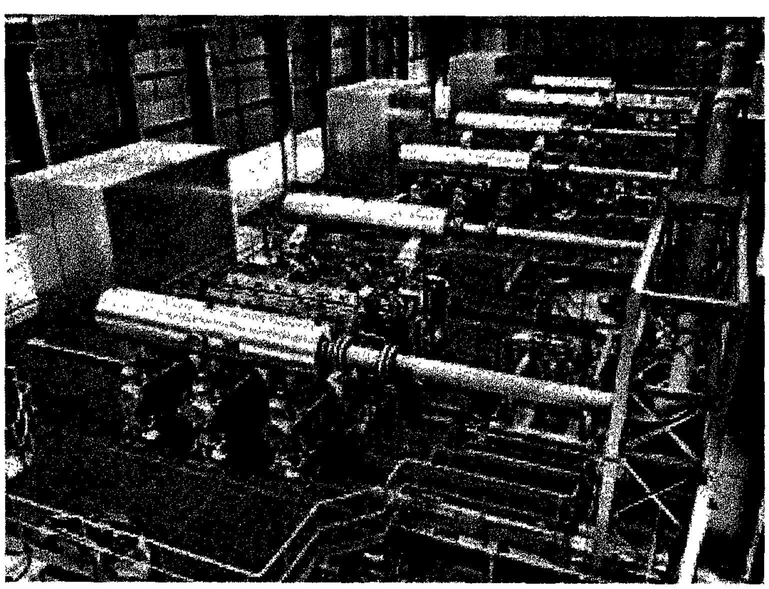
Continuous rating:
10 MW, 500 ... 5222 rpm

Short-time rating:
13 MW, 5700 rpm

Compressor hall
with 3 reciprocating compressors equipped with MEGADRIVE-LCI in a natural gas pumping station

Shaft output per drive:
4.7 MW

Speed range:
0 ... 375 rpm



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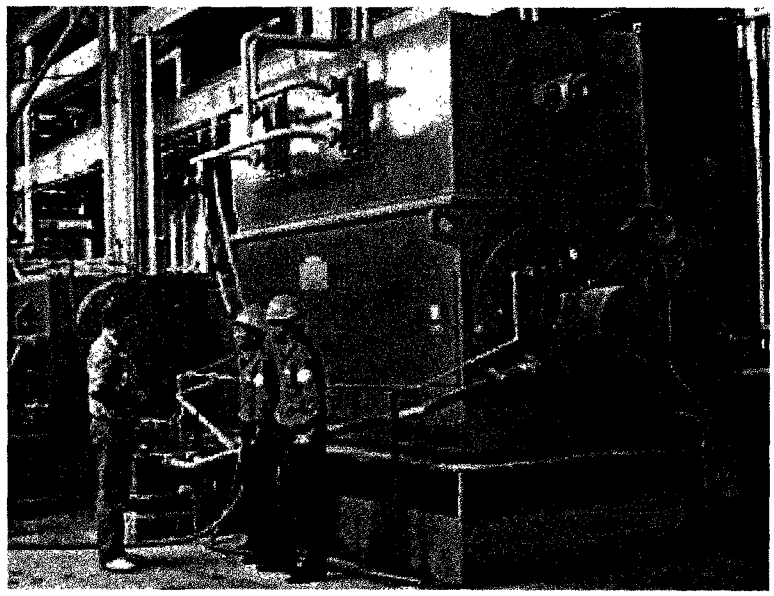


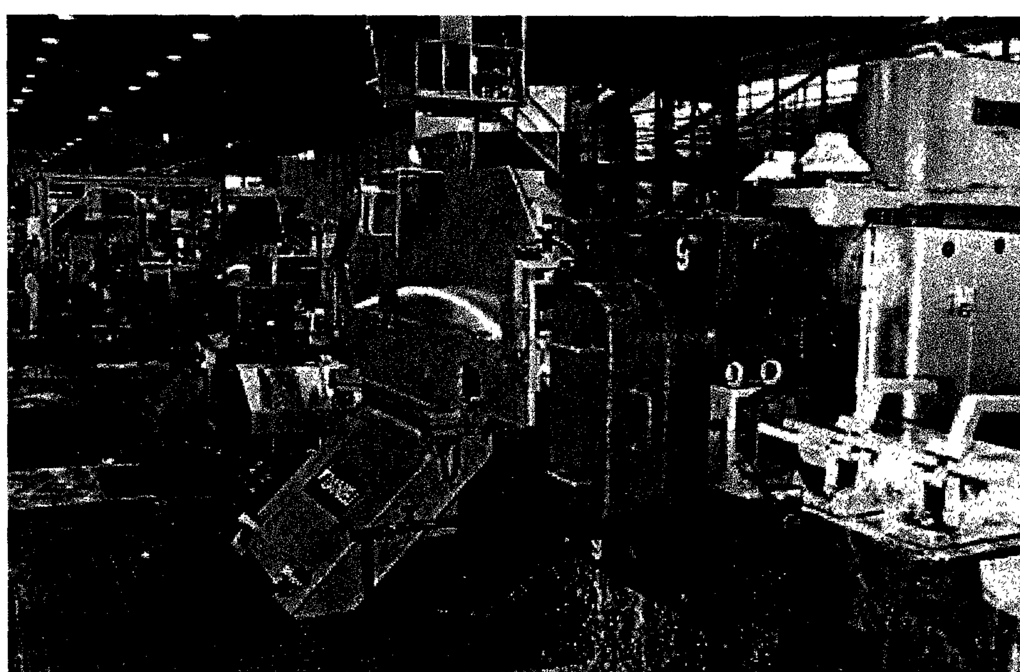
Polyethylene extruder drive
with
MEGADRIVE-LCI

Continuous rating:
5.5 MW

Torque: 44.3 kNm

Speed range:
120…1185 rpm

Wire block drive
with
MEGADRIVE-LCI



Continuous rating:
5 MW

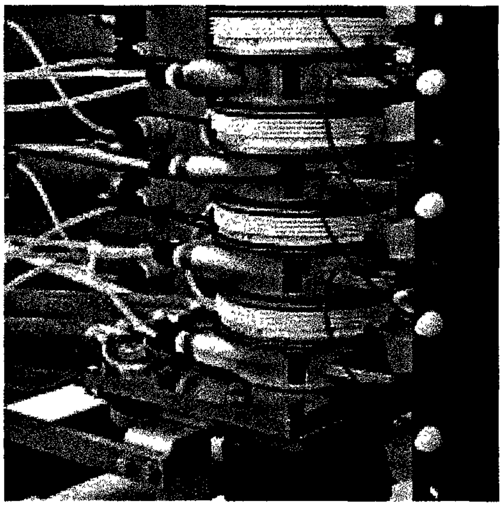
Speed range:
900…1500 rpm

Converter design and cooling

Compact and modular

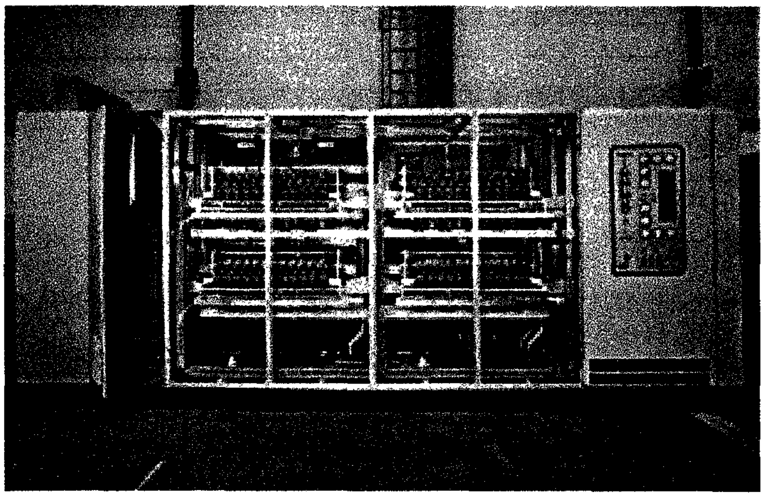
The main components of a converter are:

- thyristor stacks with thyristor heat sinks
- snubber circuits
- gate control units with either magnetic or optical fibre transmission of the control impulses
- semiconductor supervision devices
- reactors
- current and voltage transformers
- fans in the case of air cooling
- cooling unit with heat exchanger and pumps in the case of water cooling
- control and protection equipment
- excitation system
- local control panel



Part of a water-cooled thyristor stack

Both the power and control sections of the converter are constructed as modular units. For powers up to 22 MW, all the modules are mounted on a common base frame and fully metal clad and are shipped as a single unit. Converters for higher ratings are broken down into suitable units for shipment.



Water-cooled MEGADRIVE-LCI Rated power: 5 MW

The standard DIN enclosure protection class is IP30 for water-cooled converters and for air-cooled converters.
Special enclosures and proofing are available to comply with higher protection classes.

The advantages of modular construction are:

- compactness and robustness
- fast erection on site
- adaptability to the customer's needs
- ease of maintenance
- simple replacement of components
- easy to handle and ship

High voltage for high power

At the lower end of the power range, a single thyristor per branch is usually sufficient. Higher powers are generally achieved by connecting thyristors in series to divide the voltage rather than in parallel to share the current. The series connection of thyristors or thyristor bridges (e.g. for 12-pulse operation) has thus become standard practice for converters with voltage ratings up to 7 kV. Special designs are available up to 20 kV.

A high basic insulation level inside the cubicles minimises the risk of short-circuits.

The advantages of a high system voltage are:

- reduced losses because the higher power is achieved with less current
- better cost/benefit ratio for the motor
- cheaper cables with lower cable losses
- fuses can be avoided.

Efficient cooling means higher reliability

Air-cooling

- Open-circuit:
  Fans force the cooling air through the thyristor heat sinks.
  This method is suitable in plants with clean air conditions.
- Closed-circuit:
  The cooling air circulates in a closed circuit inside the converter cubicles. The air in the closed cooling circuit is cooled by an air-to-air or air-to-water heat exchanger.
  This method is necessary in plants with dusty and/or aggressive atmospheres.

The advantages of air cooling are:

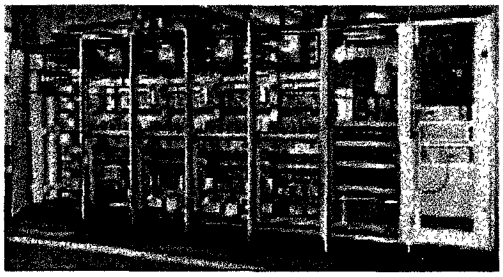
- simplicity
- overload capability for short duty cycles
- permits converters to be installed where cooling water is not available.

Water-cooling

Deionised water flows in a closed-circuit through the thyristor heat sinks and around the snubber circuit resistors and is cooled by either a water-to-water or water-to-air heat exchanger. This method is necessary for high-power applications and in plants with dusty and/or aggressive atmospheres. Circulation pump, monitoring devices for flow, temperature and conductivity are part of the converter assembly. No cooling water pipes have to be disconnected or drained in order to replace a thyristor.

The advantages of water cooling are:

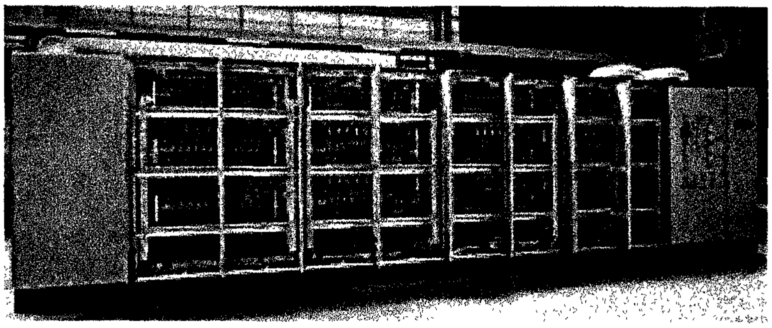
- space-saving layout
- losses easily conveyed from control room
- higher ambient temperature permissible
- less noise
- fully enclosed cubicle with protection class up to IP55 (protection against dust and splash water) for noise reduction and severe ambient conditions available



Air-cooled MEGADRIVE-LCI driving a boiler feed pump in a nuclear power plant

Rated power: 3.4 MW

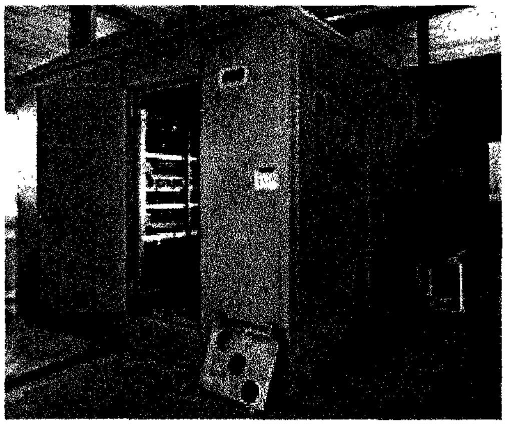
Operating mode: 12/12-pulse



Water-cooled MEGADRIVE-LCI driving a natural gas compressor

Rated power: 41 MW

Operating mode: 12/12-pulse



Walk-in outdoor enclosure for two MEGADRIVE-LCI's driving boiler feed pumps in a power plant

Walk-in enclosure

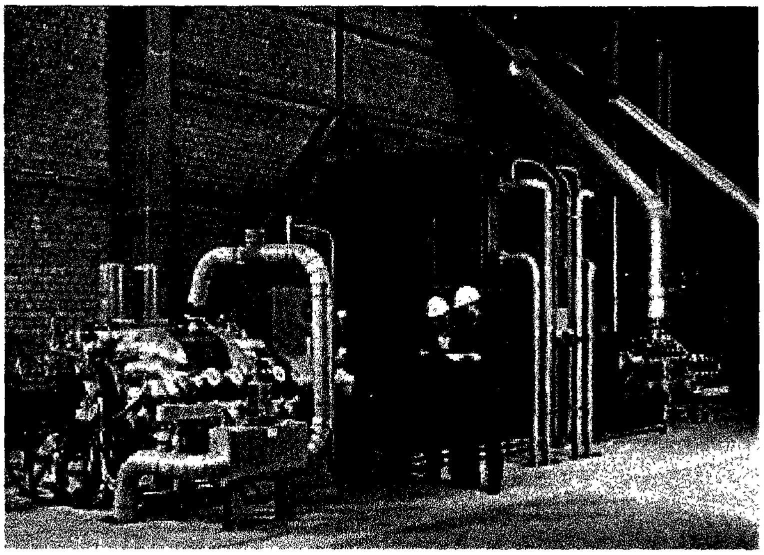
For outdoor erection, the converter complete with auxiliaries, switchgear, reactors and airconditioning plant can be installed in a fully sealed enclosure which can be supplied for varying severities of ambient conditions. All components are wired and the system tested at the works prior to delivery which considerably reduces the time required for erection and commissioning on site.

High-speed synchronous motor drives

The maximum possible speed of a directly connected two-pole synchronous motor on a 50 or 60 Hz system is 3000, respectively 3600 rpm.
Higher speeds can be obtained from a two-pole motor by inserting a frequency converter in the motor supply which applies frequencies higher than the power system frequency to it. The maximum speed possible for a synchronous motor in this kind of arrangement varies with power rating, but cannot exceed about 7500 rpm due to the constraints of the rotor and exciter design (see diagram on page 4).

High-speed drive applications
- **compressors for drives in gas and chemicals**
- **boiler feed pumps in power plants**
- **drives for test bays**

Advantages
- **no gears and therefore higher reliability and availability**
- **reduced length of shaft train**
- **much improved drive efficiency**
- **low maintenance costs**



High-speed synchronous motor driving a boiler feed pump in a power plant

Continuous rating:
10 MW

Speed range:
500...5222 rpm

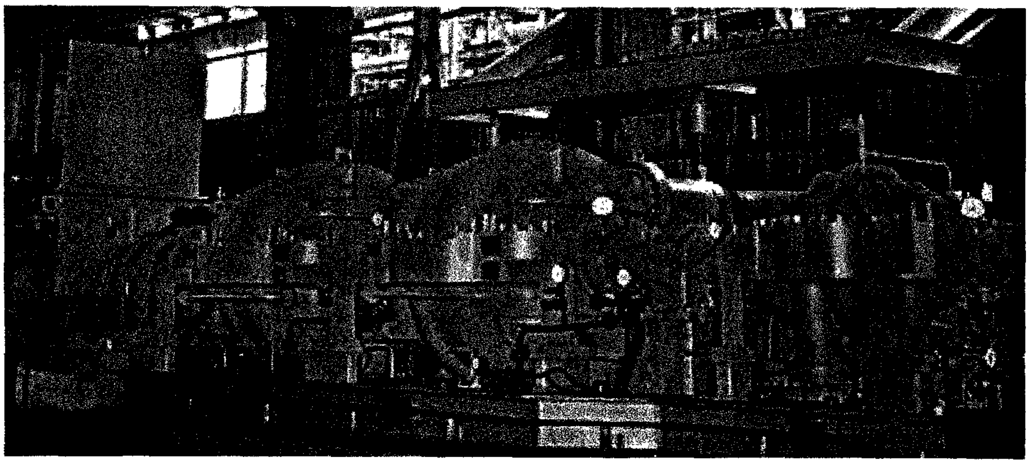
Short-time rating:
13 MW at 5700 rpm

High-speed drive references

Since the first high-speed synchronous motors with LCI frequency converters went into service at the beginning of the 80's, ABB has installed more than 60 with a total power of about 700 MW. They are used mainly for driving boiler feed pumps in power plants and large compressors in gas and chemicals and in various kinds of test bays. The individual power ratings range from 2.5 MW up to 41.5 MW and they operate at speeds up to 6500 rpm. Drives for applications in hazardous areas have been constructed to meet the corresponding standards and have been certified by authorities following extensive testing at the works. In all cases, the performance of these high-speed drives has been excellent and they are operating to the full satisfaction of the users.

Proven converter design

The LCI converter used to supply a variable voltage and frequency to a high-speed synchronous motor is basically the same as those already described for operation at normal speeds. The only difference is the higher output frequency which can be as high as 125 Hz. Both supply and machine converters usually operate in a 12-pulse mode and most are equipped with water-cooled thyristors.



Extreme left: high-speed EEx "p" synchronous motor designed for driving a five-stage compressor in a chemical plant producing ethylene

Rated power: 13 MW

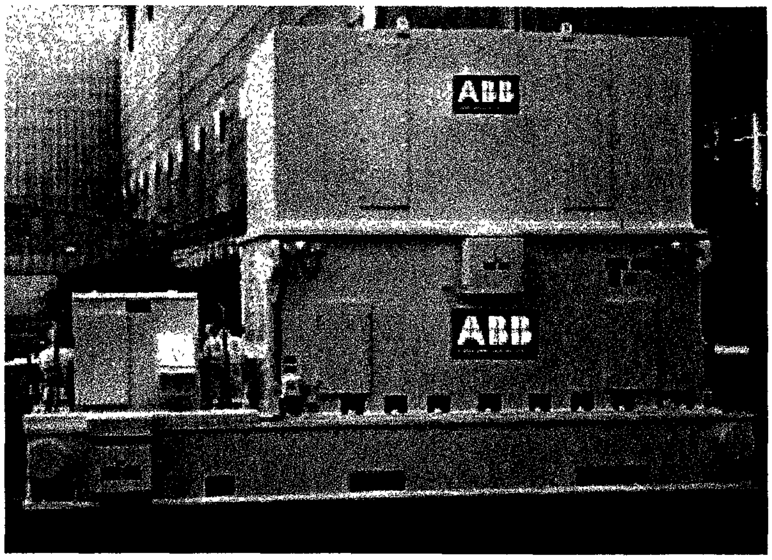
Speed range: 5700 ... 6400 rpm

In general, the mechanical and electrical design of a high-speed synchronous motor corresponds to that of a standard ABB air-cooled turboalternator slightly modified for supply by a converter.
Established methods and the experience gained over many years can thus be directly applied.
There are two sets of stator windings shifted by 30° to eliminate the 6th and the 18th torque harmonics. The cylindrical rotor is a forged monoblock in which equally spaced slots for the rotor coils are machined around the circumference. The electrically conducting slot wedges and the interconnecting retaining rings form the damper winding. The retaining rings are made of a high tensile strength non-magnetic steel alloy and oppose the centrifugal forces acting on the rotor end coils.
The exciter rotor and the diode wheel are shrunk onto the end of the shaft projecting from the motor bearing and are supported by a third bearing. This ensures that a critical whirling speed cannot occur within the normal operating speed range. Two axial flow fans provide self-ventilation and the air is cooled by an air-to-water heat exchanger.

Rotor of a high-speed synchronous motor with the exciter and rotating diodes on the left

High-speed synchronous motor

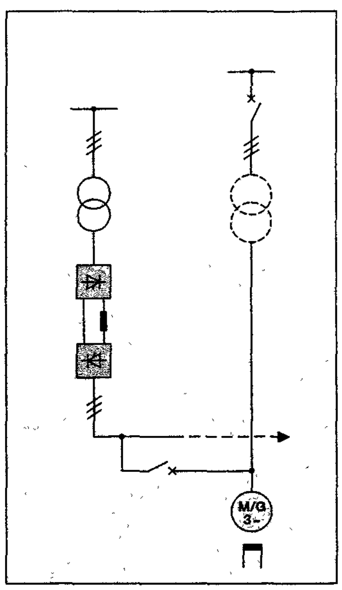
Rated power: 10 MW
Rated speed: 6000 rpm

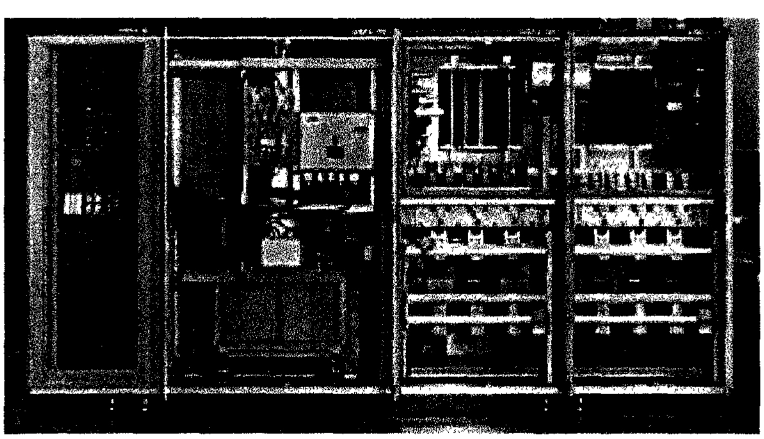


IP7_025323

MEGADRIVE-LCI.ST
Starter for synchronous machines

Starting a large synchronous machine on-line can prove problematical either because of the inrush current or because of the thermal stress at hot spots on the rotor surface while running up. These problems can be overcome with the aid of solid-state "soft" starting equipment which for this reason is being used in an increasing number of applications.





Gas turbine starting converter Type LCI.ST 3.8

Rated power: 3.8 MW

Main features
- starting current limited to the rated machine current or less
- provides facility for braking the machine
- sequential starting of several machines possible with a single soft starter
- microprocessor control system

Technical data
Typical power range: **2...80 MW**
Maximum speed: **3600 rpm (+5 %)**
Output frequency: **0...60 Hz (+5 %)**

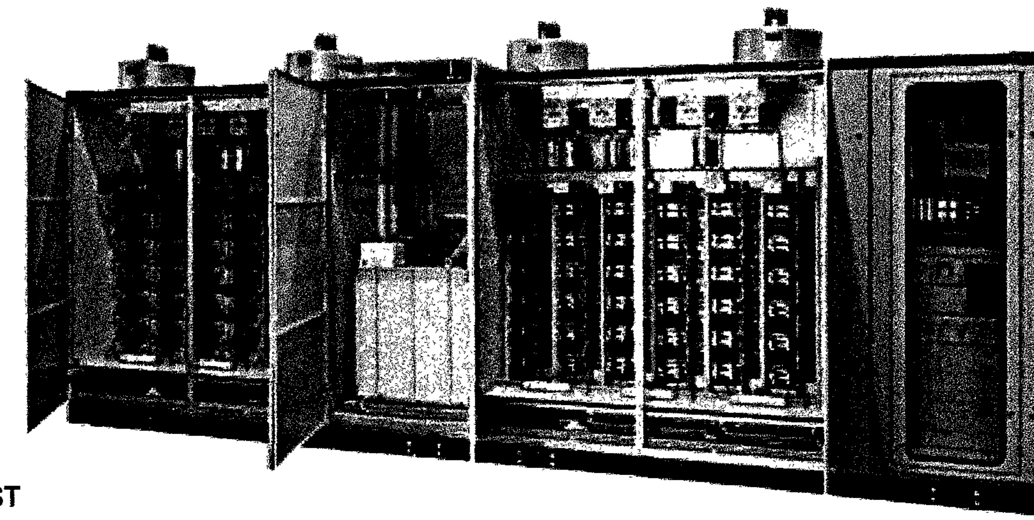
Operation
The synchronous machine is started with a variable frequency by the converter in the same way as a converter-fed variable speed motor (see MEGADRIVE-LCI). At rated speed, the machine is automatically synchronised to the power system and the circuit-breaker for direct connection to the supply is closed. The motor is excited from standstill.

Typical applications
Starting of
- gas turbines
- synchronous compensators
- refiner motors
- motor/generators in pump storage power plants
- large compressors and blowers for chemical processes

  wind tunnels

  blast furnaces

References
World-wide, ABB has installed more than 360 solid-state converters as starters with ratings between 1 MW and 60 MW. These are in use in a variety of applications and the technique has proved highly reliable for over 20 years.



MEGADRIVE-LCI.ST
Solid-state frequency converter for starting motor/generator sets in pump storage power plants

Rated power: 24 MW

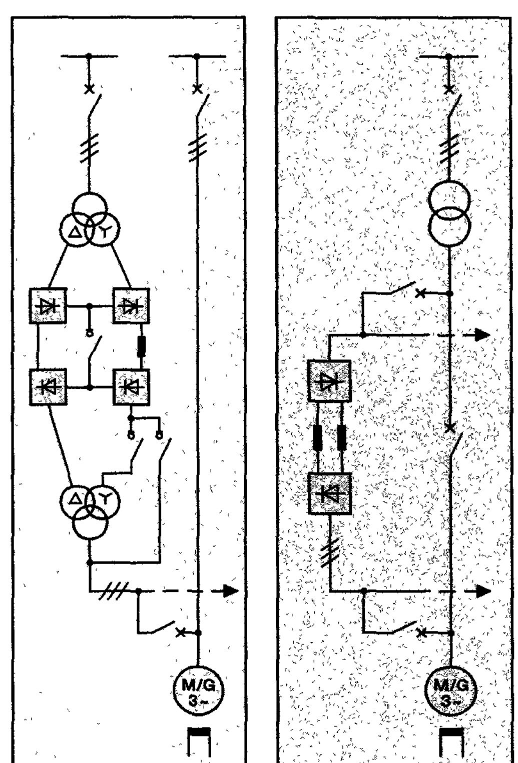
Features and options

The converter circuit is chosen to suit the particular application and requirements.

- 12-pulse supply and machine converters minimise distortion of the supply voltage and heating losses in the rotor due to harmonics
- matching transformer at the converter output
- changeover switchgear

Optional redundant components:

- (n + 1) thyristors per arm of a thyristor bridge
- separate exciter converter for starting
- Cooling ancillaries:
  Air-cooling: redundant fans
  Water cooling: redundant pump



Left: Solid-state starter with 12-pulse converters and matching transformer at the output

Right: Solid-state starter with 6-pulse converters for the rated motor voltage

IP7_025325

Engineering a MEGADRIVE-LCI-system

Engineering a converter-fed drive involves selecting and matching the motor and the converter to satisfy requirements determined by the load, the supply system, the ambient conditions and the process. Standard computer programs are employed for network analysis, harmonic filter design, simulation of transient behaviour, examination of the mechanical operation etc.

The main steps in engineering a MEGADRIVE-LCI system are:

Selection of the optimum system and circuit according to

- motor rating and speed
- motor torque/speed characteristic
- specified dynamic response
- speed control range
- power factor and voltage distortion constraints of the power system

Design of the converter components in relation to the drive parameters to optimise the system with regard to

- voltage, current and frequency
- reactances
- characteristics and number of semiconductors
- protection
- cooling
- reliability and availability
- control
- overall efficiency
- total cost

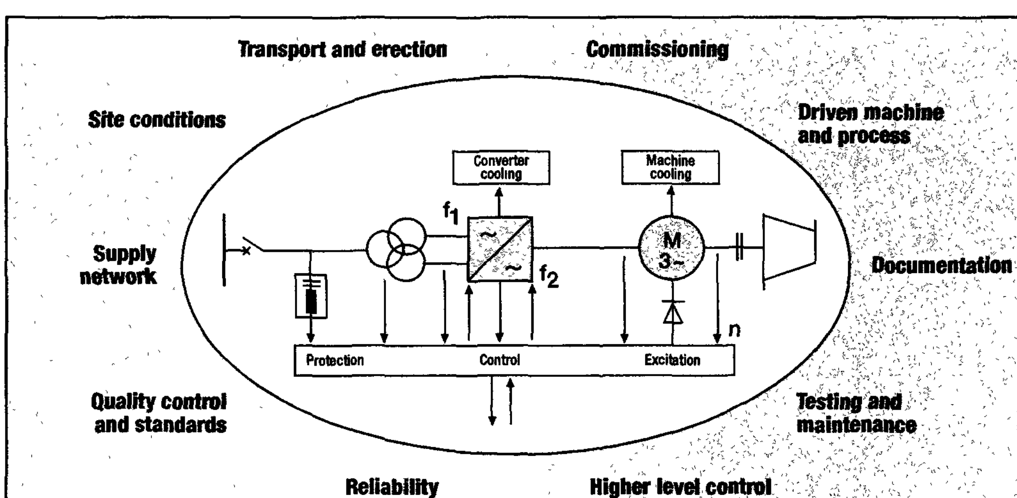
An optimum drive system can only be achieved if there is close cooperation between the machine and converter design engineers and this is given top priority at ABB. The motor design must take due account of the losses resulting from the harmonic content in current and voltage and the pulsating torque. The torsional forces exerted on the shaft train are analysed by computer to ensure proper mechanical performance.

Optimised system performance combined with high reliability and availability –

the target of our systems engineers

It is not sufficient to just consider the motor and the converter when deciding on a suitable voltage level. Overall efficiency, the switchgear and other characteristics of the specific plant have to be included as well. An understanding of the user's application, national standards and the prevailing ambient conditions on site is also essential to engineer a fully satisfying drive system.

A MEGADRIVE-system – the total solution



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Standard versions[1]	Smallest size		Largest size[2]	
	Air-cooled	Water-cooled	Air-cooled	Water-cooled
Type designation	E0806-211N4	W1212-091N4	A1212-171N4	W2x06-573N4
Input voltage [V]	2100	2x940	2x1750	2x5710
No. of thyristors in series	1	1	1	3
AC current [A]	775	1880	1410	1610
Frequency (up to) [Hz]	60	60	60	60
Motor power [kW]	2100	4660	6330	23520

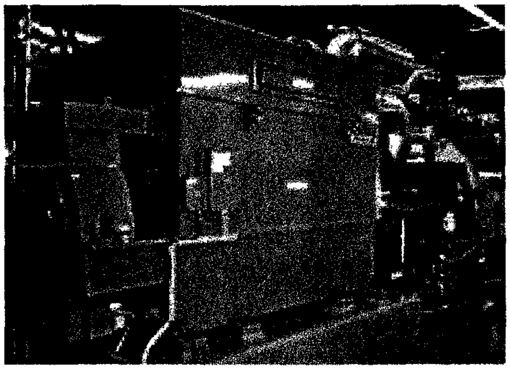
1) Data for specified conditions regarding
- power supply
- cooling
- no overload
- without redundancy
- suitable voltage and commutation reactance of the motor

2) Higher power ratings on request

Design criteria for large converter-fed AC motors

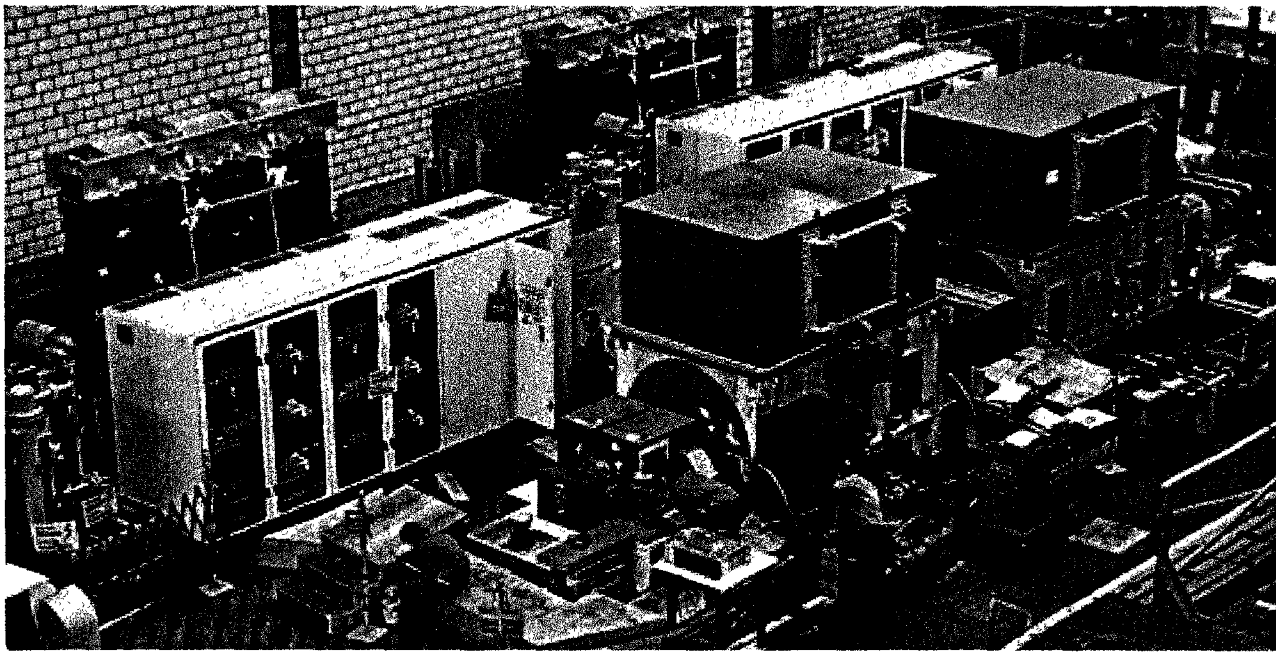
In order to guarantee the specified output and reliable operation of a large adjustable speed AC motor designed for supply by a converter, ABB pays special attention to the following:

- The motor cooling system remains fully effective throughout the specified range of speeds at the specified load.
- Full account is taken of the additional losses resulting from the harmonic content in voltage and current.
- The motor insulation is suitable to withstand the voltage waveforms including surges and du/dt phenomena which may occur in practice.
- Motor and converter voltages are chosen such that overall drive efficiency and cable costs are an optimum.
- The motor reactances are matched to converter operation.
- Where any doubt exists, a torsional analysis of the shaft train is recommended.
- The excitation system is designed to excite the machine at any speed and at standstill.
- Noise levels which are not necessarily the same as an equivalent conventional AC motor are checked in relation to the customer's specification.
- The motor protection and supervision functions are suitable for converter operation.



Synchronous motor 9 MW, 1500 rpm

MEGADRIVE-LCI under test



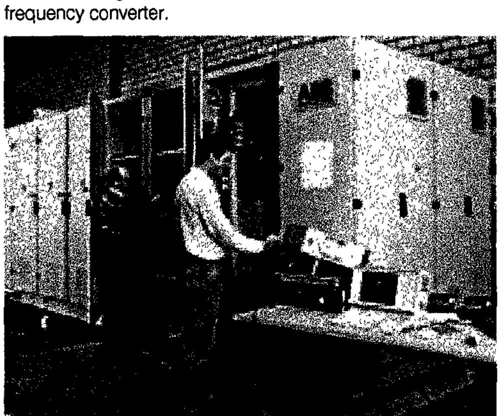
Back-to-back testing of two high-speed (6000 rpm) 10 MW MEGADRIVE-LCI drives at ABB's motor works at Birr in Switzerland. The associated converter cubicles and supply transformers can be seen behind the two motors.

Combined tests

For newly developped systems or at the customers request, the frequency converter is tested in combination with a motor at the works to verify its performance and that it conforms to the design data.

Large units are tested "back-to-back" (see picture above), i.e. one converter/motor combination drives a similar combination in a generation mode. ABB has adequate facilities to perform all these tests.

Routine testing of a frequency converter.



Load tests

Major components, sub-systems or the complete drive are tested on load to verify power or current output at rated and overload operating points under defined cooling conditions. If desired these tests can also verify the efficiency of the item concerned (segregated loss method).

Special and performance tests

At the customer's request, special tests on the complete drive system can be carried out to check the noise level, short-circuit capability, electromagnetic compatibility (EMC) etc.

Routine tests

Every component or sub-system of a drive is tested as part of the normal production process. They are carried out in accordance with international standards (e.g. IEC) and ABB quality assurance procedures (ISO 9001).

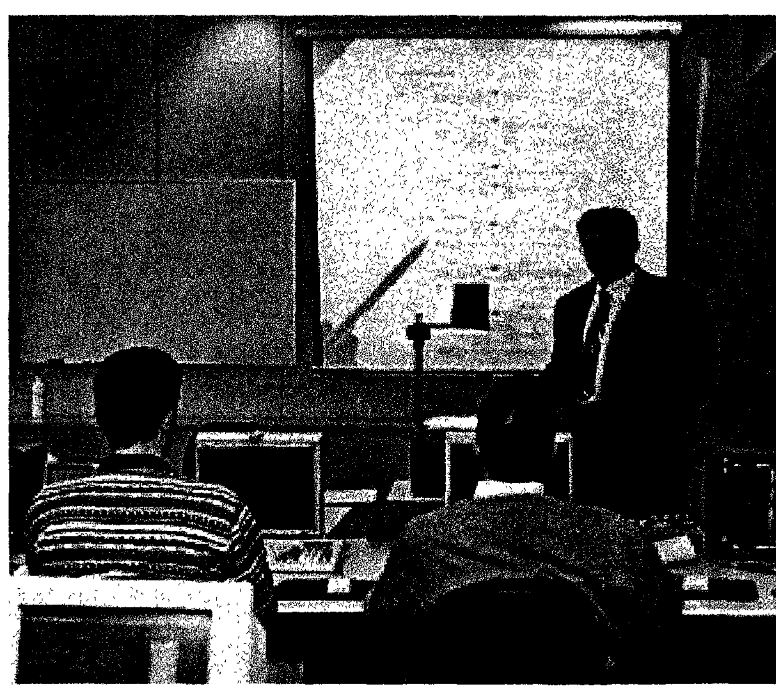
Every component of a drive is subjected to thorough testing to verify that quality standards and customer requirements are fully met. Routine tests and functional tests form an integral part of the scope of supply of a MEGADRIVE system. Where additional tests such as load tests, combined tests or special tests are considered necessary, they should be agreed as early as possible.

Erection and commissioning

The ongoing supervision of your new plant by our service department commences with its installation. Especially trained and experienced personnel make every effort to ensure that the drive is erected, commissioned and handed over on time. Erection and commissioning by our professionals is the best way to get the most out of your MEGADRIVE and extend its life.

Maintenance and trouble-shooting

Testing, repair, up-dating and fault-finding services are always close at hand and contribute to high plant availability and minimum downtime costs.
Our service centres are strategically located to provide maximum support for our customers. A hot line service telephone is on 24 hour standby.



Training

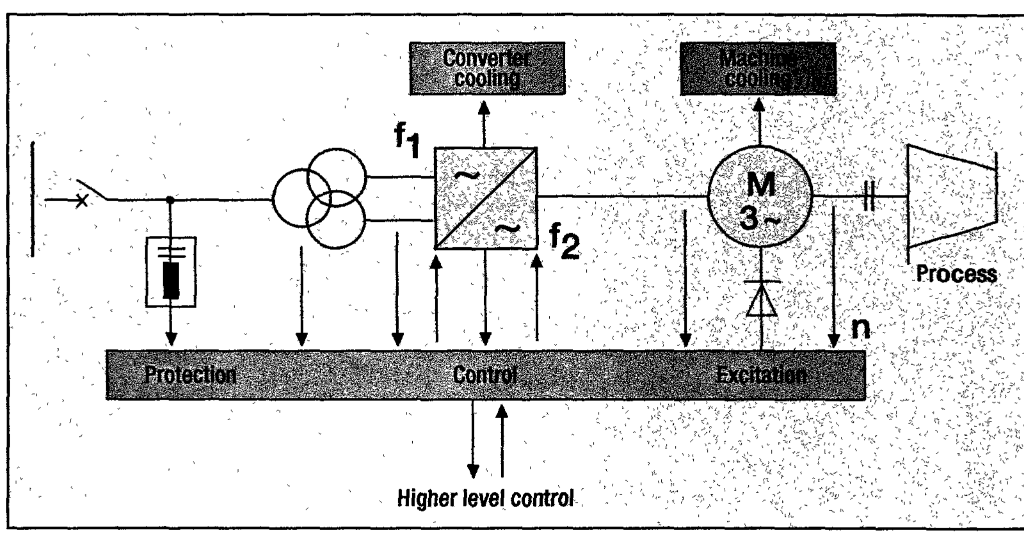
On-site training in the operation and maintenance of MEGADRIVE equipment is provided by the people who know it best – our service engineers. Training courses are also held at our engineering centres in Switzerland, Finland and other countries throughout the world.

MEGADRIVE-LCI – Scope of Supply

- Motor with exciter
- Frequency converter
- Control, protection and supervision systems
- Supply transformer and reactors
- Cables *
- Harmonic filters *
- Power factor correction devices *

** optional*

- Erection assistance *
- Commissioning *
- Mechanical analysis of the shaft train *
- Combined/load testing *
- Personnel training *
- Computer simulations *
- Maintenance contract *



Request information on other adjustable speed drives and further information on the MEGADRIVE series from your local ABB company or agent.

3BHT 490 112 R0001

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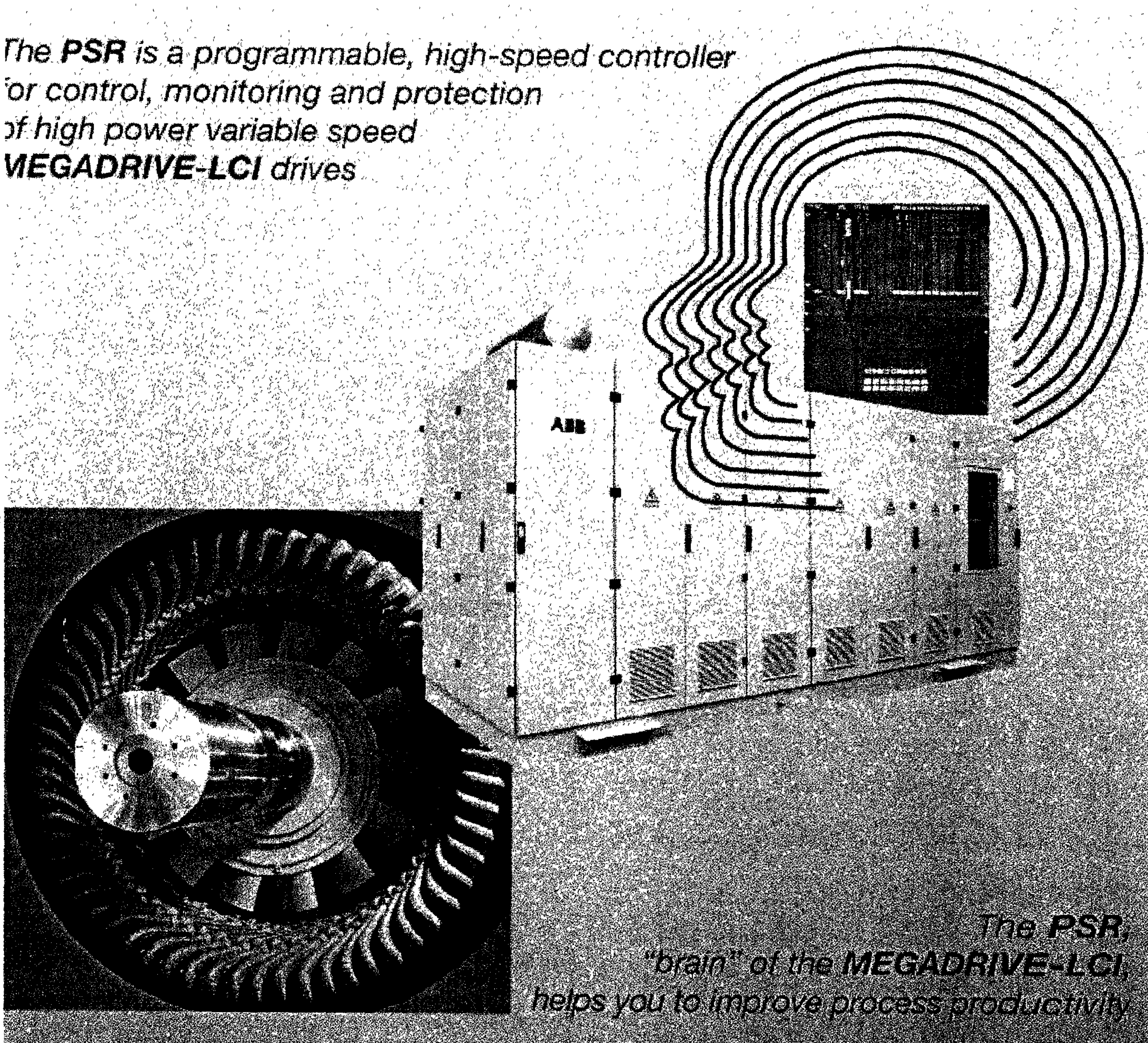
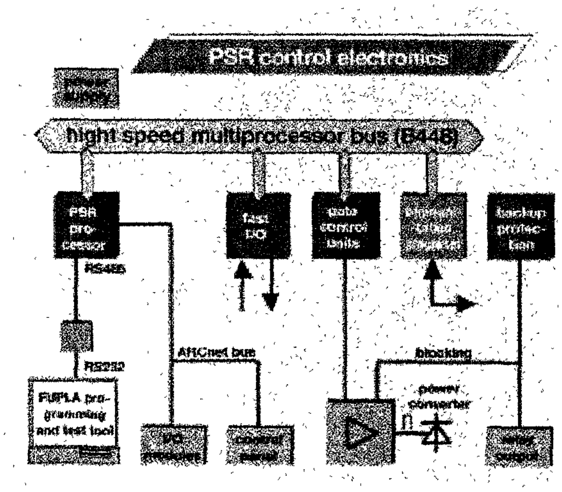
PSR control electronics for MEGADRIVE-LCI



ABB

The modules of the MEGADRIVE-LCI control electronics with PSR (a programmable high-speed controller) make up a universal control, monitoring and protection system which has been especially designed for power converter applications. Its structure is "power electronic"-oriented and the controller itself has been optimized to serve as processing node for all kinds of power electronic applications. It provides all the functions needed for this purpose, including a choice of communication interfaces to various master process control systems.

PSR controllers have been operating successfully for years in complex, high-speed control systems for
- variable speed drives (VSDs)
- static excitation systems (SES)
- high voltage DC transmission (HVDC)
- static VAr systems (SVS)
- large rectifier plants

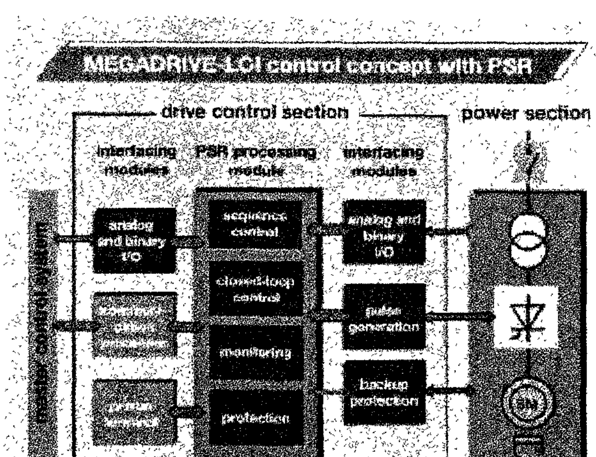


PSR control electronics

The MEGADRIVE-LCI control section

comprises three groups:
- The **processing module,** essentially a microprocessor-based digital controller, contains all programmable functions. It communicates with the interfacing modules via a fast parallel bus.
- The **interfacing with the power section** covers all analog and binary I/Os as well as all thyristor gate controls and the backup protection functions.
- The **interfacing with the master control system.** It comprises the whole signal exchange between the drive control and any master control system at the plant level as, for instance, the control room or an automation system.

Due to the high computing speed of the PSR, all control, monitoring and protection functions can be performed by a single processing unit. In spite of the high number of functions computed, several actual and set values are compared more frequently than every millisecond.



MEGADRIVE-LCI control concept with PSR

Hardware structure of the PSR control electronics

The PSR control electronics consists of different plug-in modules, such as the PSR processor, the fast interface unit and the gate control units, which are all linked together by a fast B448 parallel bus. The bus structure offers advantages not only concerning accuracy and flexibility, but also with respect to the numerous supplementary functions for diagnostic and optimization purposes.

An optional communication processor, which is also linked to this bus, makes provision for the direct exchange of data with any master control system.

An RS485 service interface is available on the front plate of the PSR processor. It is used together with a PC, for programming the PSR. It can also be used for teleservicing the drive via a PC and a modem.

PSR, the fastest function-plan-programmable processor on the market

High processing speed is necessary to perform all the drive's functions in a single processor. These functions are the closed and open loop controls, the monitoring and the protection.

Predefined function block programming is used for ease and safety of program development.

The high processing speed of the PSR processor is even more necessary if the above requirements are combined.

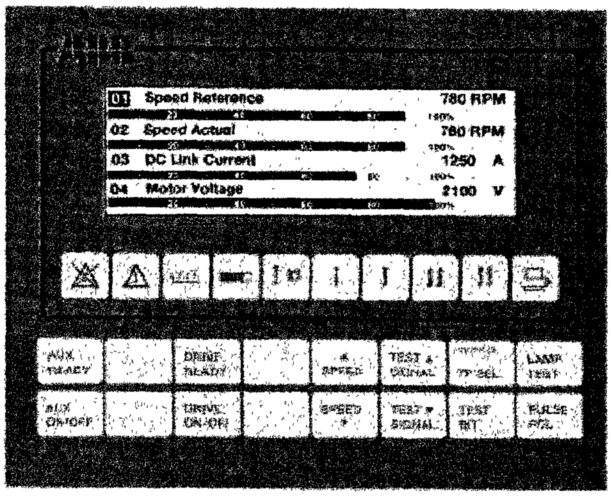
The **PSR processor** is built with two boards:
- A high-speed processing board, on which a micro-program-controlled RISC (Reduced Instruction Set Computer) with "Extended Harvard Architecture" processes the user program.
- A communication board, based on an Intel 80C186 microprocessor with an interface to the parallel multiprocessor bus B448, a coupler for the serial ARCnet bus and the RS485 service interface.

The excellent communication features result in the following advantages to the user:
- high flexibility when loading the user program and loading and viewing parameters and data
- high reliability through extensive self-monitoring
- comprehensive diagnostic and testing facilities for effective user support when testing and commissioning the drives.

Easy to operate

The local control panel facilitates drive operation and gives detailed information on the drive status.
The operator panel is a display with integrated membrane type keypad controls and it includes:
- A **display block** with eight lines and LED back-ground lighting. Two display modes can be selected: A pure alpha-numeric mode and a mixed alphanumeric/analog display mode.
- A **display control block** with one row of ten keys for controlling the functions of the display.
- An **operating block** with two rows of eight keys each, for controlling the drive system.

The functions of the panel are programmed using a PC.



MEGADRIVE-LCI control and display panel

Less wiring thanks to ARCnet®

The exchange of data within the drive system, for instance between contact inputs, relay outputs, 4...20 mA I/Os, PT100-inputs, takes place by means of a serial ARCnet bus. The operator panel for local control of the drive is also connected to this bus. The ARCnet saves space and a lot of wiring and makes extensions very easy.

Simple to integrate in any master control system

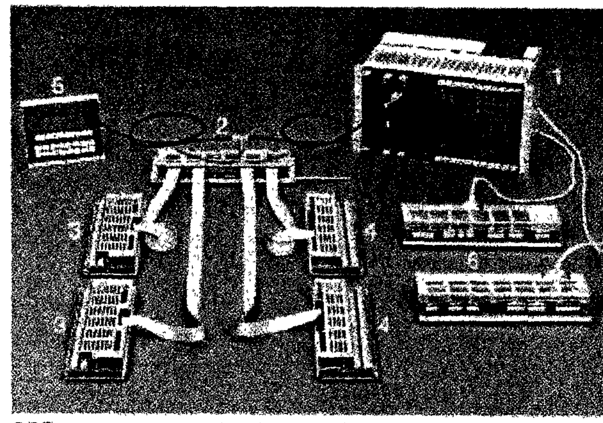
Nowadays communication with modern master control systems is a necessity.

Communication interfacing of the **standard** MEGADRIVE-LCI, for instance to the control room, is designed with analog and potential-free binary I/O interface modules, which are wired to I/O terminals in the converter control cubicle.

A separate, optionally available plug-in board with an RS485 interface provides serial data exchange with the outside world. Protocols are available for
- Modbus
- ABB Master Fieldbus
- Allen-Bradley PLC2
- Procontrol P13
- Profibus

Other protocols can be **customized** on demand.

MEGADRIVE-LCI-specific electronics



PSR control electronics for MEGADRIVE-LCI
1 PSR rack
2 ARCnet® field bus coupler with
3 two binary input modules and
4 two relay output modules
5 control panel
6 measuring interface devices

A small part of the control hardware is MEGADRIVE-LCI-specific. The major devices and components are:

- **Signal conditioning interface modules** which convert MEGADRIVE-LCI system variables, e.g. motor speed, voltages and currents, to PSR conforming signals
- **Gate control units** for the inverter
- **Backup protection modules**
- MEGADRIVE-LCI-specific backplane printed circuit board for PSR rack.

PSR software tools

Powerful software tools are needed for engineering, programming and commissioning the drive system. These tools are applied for

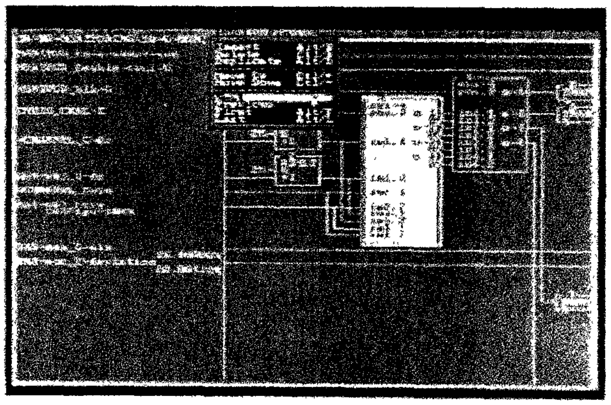
- configuring the system
- programming the drive's functions
- documentation
- setting parameters and viewing data
- diagnostic purposes

All tools run on a PC and most of them are based on a graphical programming language using function and state diagrams. This language offers a full complement of control, monitoring and protection functionality and it is a versatile instrument for supporting the system engineer.

The following software packages exist:

- **FUPLA2 system configurator and programmer** used for
  - adapting the structure of the PSR software to suit the controller hardware
  - setting up function plans with function blocks and for creating sequential control procedures
  - generating the programs and downloading them to the PSR processor via the standard RS485 service interface provided on the PSR processor.

- **FUPLA2 documenter** for creating hard copies of the program structures, of the application programs and of the signal and parameter lists.
- **FUPLA2 parameter/data viewer and modifier** for looking at signals and carrying out any necessary parameter changes. The standard RS485 service interface on the PSR processor enables the ABB service engineer to make these changes.



Function plan programming on a PC

As far as our **standard** MEGADRIVE-LCI is concerned, control structure as well as drive parameters in general are not subject to any changes by the drive operator. The application program and all drive parameters are established and set at the factory, adjusted during commissioning and stored in the drive's PSR processor EEPROM memories (electrically erasable programmable read only memory).

- **PSRView** is used to give the customer access to a subset of practical parameters like controller settings, ramps, protection limits, etc. PSRView is installed on a separate PC that accesses the drive software via the RS485 service interface at the PSR processor. The PSRView program is user-friendly with menu-prompts and on-line help functions.

PSR, a beneficial control system for all MEGADRIVE-LCI configurations

The excellent characteristics and the proven qualification of the PSR control electronics and of the pertaining software tools have beneficial effects on drive engineering, on project handling in general and also on drive operation. The consequent modular design and the standardization of both the hardware and the software make it possible to design a safe and optimal solution for any drive configuration.

The PSR manifests the following benefits to the drive user

High drive reliability
- The "all in one" controller, that provides control, monitoring and protective functions for motor, converter and transformer, has a high degree of integration that favors reliability.
- High communication density, i.e. many signals per signal channel (B448 and ARCnet), leads to high reliability.

High drive availability
- Modularity and good access for maintenance of the digital control system, together with its self-test and self-diagnostic facilities favor drive availability.
- Back-up for trouble shooting by the possibility to diagnose from a remote location via modem connection.

Flexibility and ease of operation
- Adaptability of the drive controls to master controller requirements.
- The user-friendly panel simplifies drive operation and trouble shooting.

Low risk
- Practically no software errors due to its modular design and its standardization.
- Field experience gained with more than a thousand units installed in power electronic applications.

All these benefits lead to **improved drive performance and higher profitability** of the process.

3BHT 490 290 R0001

We reserve the right to make changes in the course of technical development.

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Appendix: Recommended Spare Parts for LCI.DR

C: Commissioning Spares
N: Normal 2-5 years Operation

Project: Intermountain Service Corporation

Recommended Spare Part List
(C: for commissioning; N: for normal operation (2-5 years))

Part Typ	Part Description	m = modified		BR1-A1212-604R452	BR1-A1212-604R452	
				C	N	
Control						
MPS 10/5-230/24/48	Power Pack 100-240Vac/dc//24/48Vdc/250W			1	1	
AF C094 AE02	Operation Panel	m		1	1	
AR C093 AE01	Output Relais 16 Fold			1	1	
CS A463 AE01	Supervision Analog	m		1	1	
CS A464 AE01	Supervision SR-SYMO	m		1	1	
FM 9925 AE1	Angle Shifter			1	1	
GD 9924 BE V2	SRM Trigger Unit			1	1	
GD B021 BE01	Gate Control Unit			1	1	
GD C780 BE21	B448 Interface to LINT/PINT			1	1	
HZ C075 A	Fan Tier 24V DC			1	1	
NU 8976 A99	Power Pack			1	1	
PM A324 BE01	Master-AZP			1	1	
PP C322 BE01	PSR2 Processing Unit	m		1	1	
SA 9923 AE01	Reference Voltage Generator	m		1	1	
UA C395 AE01	PT100-Monitoring					
UA C096 AE01	Analoge I/O (arc)			1	1	
UA C317 AE01	Measuring Device 1	m		1	1	
UA C318 AE	Measuring Device 2	m		1	0	
UA C326 AE01	Combi I/O			1	1	
UF C092 BE01	Binary Input 16 Fold			1	1	
UP C090 AE01	Binary Field Bus Coupler			1	1	
	Set of MCBs, Breakers				1	
	Set of small mech. parts			1		
Power Part						
DD C330 BE04	MV-LINT (ns=4,5,6)			1	1	
XV C517 AE10	MV-GDR (no BOD)			1	2	
	Thyristor 5.2 kV, 5STP 3452N0019			2	8	
	Snubber Resistor				2	
B25835-S2205-K7	Capacitor 2uF; +/-10%; 3.1kV				2	
1BK/300	Fuse; 6kV / 32A			2	3	
POLIM-C 6.0	Overvoltage Limiter; 6kV			2	3	
	Thyristor changing tool (air cooled conv.)			1	1	
Excitation / AC-controller						
	Contactor					
	Fuses			4	4	
	AC-controller				1	
Air Cooled Converters						
	Converter Fan				0	
	DC-Reactor Fan				0	
ES2-S	Diff. Pressure Switch; 0.2-2mbar; 250V/1A				1	
Total costs						